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ANALYSIS OF A PROPOSED WHOLESALE
REPAIRABLES REPLENISHMENT MODEL

by

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December 1986

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Analysis of a Proposed Wholesale Repairables Replenishment Model

by

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ABSTRACT

This thesis analyzes a proposed new Navy wholesale level repairables replenishment model with specific focus on procurement lot size (Q) because of its direct relationship to inventory control point workload. The model is also tested with real-world data.

Results emphasize the trade-offs between wholesale investment levels and order quantities and mean supply response time goals.

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I. INTRODUCTION

A. BACKGROUND

The Naval Supply Systems Command, and more specifically its inventory control points (ICPs), are facing a significant challenge. To date, increasing defense dollars have been authorized and appropriated for both old and new weapon systems and their support. However, recent Congressional enactments and deficit reduction measures have mandated future cutbacks in defense spending. This has included funds for both hardware and personnel. It has become imperative that maximum measurable benefits be received from each dollar and each manhour expended/invested.

The Navy will be tasked with continuing to demonstrate improvements in readiness and sustainability of a six hundred ship Navy with decreases in supporting resources. The availability of spare parts, both consumable and repairable, will be increasingly critical to operational readiness. It is therefore essential that the proper management of spare parts remains as a top priority within the Naval Supply Systems Command.

New ships and aircraft being introduced into the fleet have reflected the rapid advances in technology in weapons and electronic systems. Installed equipment is increasingly sophisticated. Likewise, concern for the support for this equipment has put new emphasis on repairables management and, in particular, the management of depot level repairables (DLRs). NAVSUP Publication 553 [Ref. 1] defines DLRs as items which are returned to the Navy's wholesale supply system for repair when they fail in use. The responsibility for the wholesale management of repairable items is assigned to the Navy's two inventory control points (ICPs), the Ships Parts Control Center (SPCC), Mechanicsburg, PA. and the Aviation Support Office (ASO), Philadelphia, PA.

As a consequence of the Resystemization Project, which is replacing the ICPs outdated computers, an opportunity was provided to look at the ICPs' software and models [Ref. 2]. Improvements in the wholesale level provisioning and replenishment models were assigned to Professors Richards and McMasters at the Naval Postgraduate School. They began the improvements to the provisioning model in

1982. Because of the current pressure from Congress and the Department of Defense to have all models relating resources to combat readiness, they proposed a model which minimized mean supply response time (MSRT) subject to a budget constraint. This model was formally accepted by the Navy in December 1984 [Refs. 3,4,5]. In the summer of 1984, their attention shifted to a repairables replenishment model which would provide for the sustained management of inventories once they had been bought using the new provisioning model. Obviously, a model involving mean supply response time was appropriate for replenishment also. The basic structure of a multi-echelon repairables inventory replenishment model was presented by Apple [Ref. 5] in March of 1985. MSRT was chosen by Apple as the objective function for replenishment of repairable items at the wholesale level. Gormly [Ref. 6] expanded Apple's work by converting it to an aggregate-demand model representing the way demand is currently viewed at the ICP level. His objective was to seek to minimize wholesale stock investments subject to budget constraints and a mean supply response time goal. His model serves as the basis for this thesis.

B. OBJECTIVES

Gormly [Ref. 6] presented a replenishment inventory model for management of repairable items at the wholesale level that considered Congressional budget constraints as well as readiness. However, discussions with personnel from the ICP's have emphasized that workload constraints are becoming increasingly more critical than budget constraints. Therefore, the objective of this thesis is to study the impact on the aggregate-demand replenishment model of varying the procurement lot size (Q) since the quantity procured has the major impact on ICP workload. In addition, the model will be tested using real-world data for the first time.

C. PREVIEW

A brief review of the wholesale repairables system is provided in Chapter II. It is followed by a detailed review of the aggregate demand model presented by Gormly. The model is then changed to consider two values; one with Q equal to annual attrition demand and the other equal to the ICP's current economic order quantity (EOQ). The repair induction quantity is set to 1.0 to reflect the current ICP practice of one-for-one carcass inductions by the designated overhaul points (DOPs). Chapter III describes

the application of real world data to the aggregate demand replenishment repairables model. This includes a discussion of the problems encountered while reprogramming the model to incorporate the use of real-world data. The results attained from setting Q equal to annual attrition demand, EOQ and 1.0 listed and compared. Finally, the impact of mean supply response time on wholesale investment levels is analyzed. Chapter IV provides a brief summary, some conclusions from the analysis, and recommendations of areas for further study of the aggregate-demand model.

II. THE REPAIRABLES SYSTEM

A. DESCRIPTION

Currently, a system component is designated as a repairable if its repair time is less than its procurement time and/or if its repair cost is less than one hundred percent of its replacement cost. The management of repairables begins at the outset of a new weapon system program through a level of repair analysis (LORA) and continues through the procurement process and the repair cycle. This complete management system is called the repairables system.

There are three maintenance levels in which repair actions may occur: (1) the organizational or lowest level (i.e., a ship); (2) the intermediate level (i.e., a tender, carrier, or a shore intermediate maintenance activity); and (3) the depot level (i.e., naval shipyard, industrial naval air rework facility or a commercial repair activity). Figure 2.1 depicts the "repairables cycle" for a depot level repairable (DLR) item.

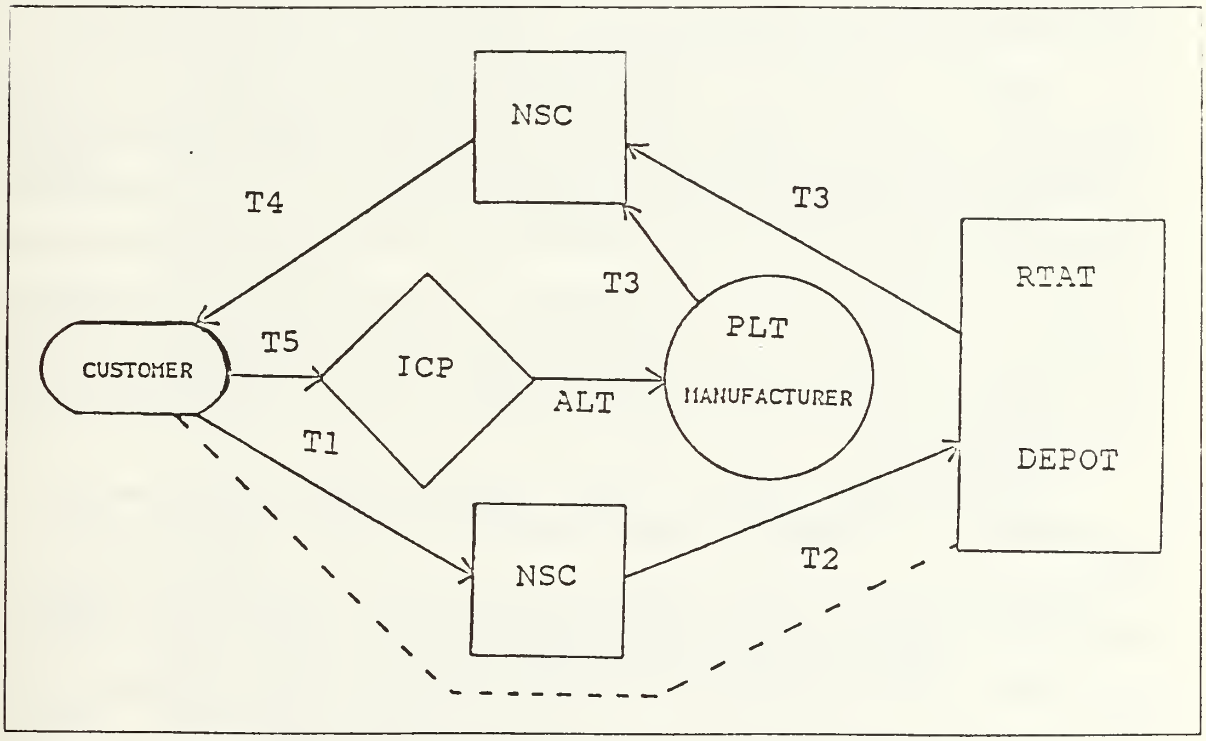


Figure 2.1 Repairables Cycle.

The process begins when the customer submits a requirement (demand) for a DLR to the nearest stock point / naval supply center (NSC). If the item is available directly from that activity, it is issued to the customer. The demand for an item that is not available for issue is referred to the inventory manager at the ICP. The requisition is then either referred to another activity holding the item or is recorded as a backorder against stock that is under repair or being procured.

The inventory manager and, increasingly, the customer are concerned with the prompt turn-in of the failed not-ready-for-issue (NRFI) carcass. The customer is concerned about the financial impact of any mishandling of costly repairable carcasses since he knows that he will not be charged for quickly returning a carcass in good condition. The inventory manager is concerned with limited resources and long procurement and repair lead times while trying to fill all system demands. Resources may be limited due to a failure to provide adequate spare parts provisioning packages at the outset of a major weapon system program or may be the result of stock fund budget considerations. Procurement lead times of as many as four years for some items are now occurring and pressures are being applied to depots to reduce their repair turn-around times. This makes planning by the item manager extremely difficult and often can actually be little more than a "best guess" as to future availability.

Whereas the current ICP replenishment model has assumed the accumulation (batching) of NRFI carcasses at a stock point until a predetermined batch size is available for repair induction, the actual repair process for a DLR is continuous. A single NRFI carcass is shipped to a specified stock point or Designated Overhaul Point (DOP) for repair as soon as it is returned from the customer. Once repairs are complete, the DOP ships the ready-for-issue (RFI) unit to the stock point or directly to the customer as directed by the inventory manager. The time between repairs is called the "repair cycle."

While the repair cycle is of prime concern to the inventory manager, it is recognized that a percentage of carcasses will not be returned to RFI condition. This may be due to a customer's failure to turn an NRFI carcass into the system, mishandling enroute, or the carcass being beyond economic repair. Thus, the procurement of replacement units must be planned to compensate for this attrition. The time between procurements is called the "procurement cycle."

The variables listed below, as defined by Gormly [Ref. 6], represent the elements of the repair and procurement cycles.

Q : Procurement quantity. In this analysis, two values for Q are considered; annual attrition demand and the EOQ;

T1 : Carcass turn-in time; i.e. the time it takes for a carcass to be received at the collection point (NSC) after a demand has been registered (this includes customer turn-in time and shipping time);

T2 : Shipping time for a carcass from the NSC to the DOP;

T3 : Shipping time for an RFI unit from the DOP or a manufacturer to the NSC;

T4 : Shipping time for an RFI unit from the NSC to a customer;

T5 : Time required for the ICP to determine that a carcass will not be returned from the customer to the system;

RTAT : Time required for the DOP to repair an item or a batch and return the batch to RFI condition;

ALT : Administrative lead time required by the ICP to prepare purchase documentation and a purchase order to negotiate a contract to purchase a replacement item;

PLT : Production lead time required by the manufacturer to produce the quantity of an item being purchased;

PCLT : (Procurement Leadtime): ALT + PLT + T3;

CRR : (Carcass Return Rate) Rate at which NRFI carcasses are returned from the customer to the wholesale system for induction into the repair process;

CRT : (Carcass Return Time) The sum of T1 + T2;

D : Quarterly demand (or failure rate);

SW_i : Wholesale stock level of item (i). This includes on hand, in-repair and carcasses awaiting repair. In the model, it is the value of the inventory position. Therefore, it includes outstanding procurements as well;

MSRT : MSRT(SW_i) Mean supply response time for the wholesale system for item (i) when the wholesale stock level of item (i) is SW_i;

ROP : Replenishment reorder point

RSR : (Repair Survival Rate) Rate at which NRFI carcasses survive the repair process and return to RFI condition;

TWUS : Time weighted units short per unit time. (Expected number of backorders for an item at a randomly selected time);

B. THE AGGREGATE DEMAND MODEL

1. Gormly's Thesis

Gormly [Ref. 6] provides a synopsis of Apple's descriptions of the mathematical models in use today for the management of repairables at the Ships Parts Control Center (SPCC) and describes the multi-echelon structure developed by Apple. He then builds upon the multi-echelon structure and develops an aggregate demand replenishment inventory model. This chapter provides a detailed overview of Gormly's model. The FORTRAN programmed aggregate demand model presented by Gormly is included as Appendix A. The model was run with the WATFIV compiler on the IBM 3033 at the Naval Postgraduate School.

2. Aggregation of Demand

SPCC is concerned with the management of the wholesale supply system based on an aggregation of demand from a diverse customer base (i.e., ships, shore stations, foreign military sales (FMS), other branches of the Department of Defense, etc.). This aggregate demand is currently forecasted by the Uniform Inventory Control Programs (UICP). The UICP is a large conglomeration of computer programs developed by the Fleet Material Support Office (FMSO) to provide the ICPs with in-depth inventory management techniques. The aggregate demand is forecasted at the end of each quarter using an exponential smoothing model. This forecast is an estimate of the demand or failure rate D_i.

C. THE MODEL

The total related monetary value or investment level of wholesale stock carried in the system can be written as:

$$\sum_{i=1}^{n} C1_i * SW_i$$

where

$C1_i$: unit procurement cost or price of item i;

SW_i : wholesale stock level for item i.

This sum also represents the value of the Navy's Stock Fund. This fund is a revolving fund managed by the Naval Supply Systems Command. It is reimbursed by the customer coincident to issue from system stock and is augmented by Congressional appropriation.

In recent years, mounting pressure from the Congress and Department of Defense to relate the total stock fund corpus to measures of readiness has prompted the Navy to shift its emphasis to this effort. The supply system's part of the readiness puzzle is supply response time. Its average value is the definition for MSRT. While the ideal goal would be achieve the lowest possible MSRT (i.e. zero, where all items are always immediately available), funding generally has constrained the size of Navy Stock Fund (NSF) inventories. Because of the trade-off, which is obvious, between MSRT and the NSF corpus, the problem can be formulated in two different ways. One way is to minimize MSRT subject to a budget constraint; The other is to minimize the total value of the NSF while attempting to achieve an MSRT goal. Apple chose the first formulation; Gormly chose the second.

While Apple's model [Ref. 5] included consideration of a "linear" essentiality code (E_i) in the replenishment problem, Gormly [Ref. 6: p.27] chose to use Item Mission Essentiality Codes (IMEC). Recognizing, however, that IMEC categories did not necessarily equate proportionally to an item's relative criticality, he followed the current ICP approach and assumed a separation of all items into IMEC categories and assignment of appropriate MSRT goals for each level. Gormly then sought to find that depth SW_i for all items $i = 1, 2, \ldots, n$ in a given IMEC code which

minimizes:

$$\sum_{i=1}^{n} C1_i * SW_i \qquad \text{(eqn 2.1)}$$

subject to

$$\sum_{i=1}^{n} D_i * MSRT_i(SW_i) / \sum_{i=1}^{n} D_i \leq \text{MSRT Goal}$$

where

$MSRT_i (SW_i)$ = the mean supply response time of the wholesale system for item (i) when the wholesale stock level of item (i) is SW_i.

As shown by Hadley and Whitin [Ref. 7: p.185], the expected number of backorders at a randomly selected point of time is equal to the total expected time-weighted units short (TWUS) per quarter. The formula for $TWUS_i$ when SW_i is stocked is:

$$TWUS_i\,(SW_i) = (\mu_i - SW_i) + \sum_{x_i=1}^{SW_i} (SW_i - x_i) * p_i(x_i;\, \mu_i). \qquad \text{(eqn 2.2)}$$

where μ_i is the mean number of units in resupply. Richards and McMasters [Ref. 3] showed that

$$MSRT_i\,(SW_i) = TWUS_i\,(SW_i) / D_i \qquad \text{(eqn 2.3)}$$

The actual mean supply response time corresponding to a given level of wholesale system stock SW_i is the sum of the shipping time to the customer, T4, and the mean supply response time of the resupply cycle (repair plus procurement), or:

$$T4 + MSRTS_i\,(SW_i),$$

where $MSRTS_i\,(SW_i)$ = mean supply response time for the resupply cycle. However, Gormly assumed that T4 was zero since shipment of an RFI unit to a customer could be expected to take negligible time relative to RTAT and PCLT. Thus, the actual $MSRT_i$ reduces to Equation 2.3 . The MSRT goal constraint then takes the form:

$$\sum_{i=1}^{n} TWUS_i\,(SW_i) \,/\, \sum_{i=1}^{n} D_i \leq \text{MSRT Goal} \qquad \text{(eqn 2.4)}$$

A key parameter of Equation 2.2 is μ_i , the mean number of units in resupply. Now, μ_i can be written as:

$$\mu_i = D_i * Mu_i \qquad \text{(eqn 2.5)}$$

where Mu_i is the mean resupply cycle time. The formula for Mu_i, from [Ref. 6], is

$$\begin{aligned} Mu_i = {} & (RSR * CRR) * (CRT + RTAT + \\ & ((R-1) / (2D * (RSR*CRR))) + (1-(RSR*CRR))* \\ & (PCLT + (Q-1)/(2*D*(1-(RSR*CRR)))) \end{aligned} \qquad \text{(eqn 2.6)}$$

Substituting Equation 2.6 into Equation 2.5 and simplifying gives:

$$\begin{aligned} \mu = {} & D * (RSR * CRR) * (CRT + RTAT) + (R-1)/2 + \\ & D * (1 - (RSR*CRR)) * (PCLT) + (Q-1)/2. \end{aligned} \qquad \text{(eqn 2.6)}$$

The ICPs refer to the sum of the terms containing D as the Procurement Problem Variable, or PPV. Thus, we can finally write

$$\mu = PPV + ((R-1)/2) + ((Q-1)/2). \qquad \text{(eqn 2.7)}$$

Values for all parameters in Equation 2.6 are available from forecasted and historical data maintained in the UICP files. The repair induction (R) and procurement (Q) quantities were assumed to be parameters to be input by the analyst. For this thesis, R will be set to 1 and Q will be varied between annual attrition demand and economic order quantity.

Once μ_i is known, the total expected time-weighted units short (TWUS) per quarter for each item can be calculated by recalling Equation 2.2.

The iterative search for SW_i which solves the optimization model (Equation 2.1) made use of the technique of marginal analysis. The first step is to set all SW_i to zero. $TWUS_i$ for $SW_i = 0$ is then computed for all items. The results and each item's forecasted demand were combined as shown in the left-hand side of Inequality 2.4 to

arrive at the system-wide MSRT provided when SW_i was set equal to zero for all items. This calculated MSRT, (which Gormly denoted as CMSRT), is compared to the MSRT goal and, if the CMSRT is less than or equal to the MSRT goal, no further calculations are needed. Optimal SW_i is zero for all i.

If CMSRT, when all $SW_i = 0$, is greater than the MSRT goal, a ratio; WT_i, is computed for each item i. It is the ratio of an item's unit cost and the change in the expected time-weighted units short for an increase of one unit in SW_i for an item. This ratio is given by :

$$WT_i = C1_i / (TWUS(SW_i - 1) - TWUS(SW_i)) \qquad \text{(eqn 2.8)}$$

WT_i expresses the increase in investment cost of each item relative to the benefit in reduced response time derived from adding one additional unit of the item to the wholesale stock.

For each item being considered, WT_i was computed assuming $SW_i = 1$ and then one unit was added to that item k for which $WT_k = \min \{WT_i\}$. A check is then made to see that the MSRT goal is also satisfied. This is done by computing the left-hand side of the constraint (Inequality 2.4) and comparing it to the MSRT goal value. If the computed MSRT is still greater than the MSRT goal, a new value of WT_k is computed by assuming now that $SW_k = 2$ before comparing it with other WT values. That item having the smallest WT_i is selected and its wholesale level is increased by one unit.

This process of increasing SW_i , computing ratios and increasing the SW_i for that item having the lowest WT_i value continues until the computed MSRT is less than or equal to the MSRT goal. Finally, with all SW_i values known from this last step of the marginal analysis procedure, the value of the objective function can be computed by summing the products $C1_i*SW_i$ over all items. This provides the minimum total investment required to meet the given MSRT goal.

1. Values of Q and R

The variable in the aggregate demand replenishment model which plays the most significant role in ICP workload scheduling is the procurement lot size (Q). Its impact upon the wholesale stock levels (SW) required to achieve the specified MSRT

goal is of considerable significance. A brief discussion concerning Q and its relationship to the aggregate demand model and to current budgetary practice in the Navy is appropriate prior to analysis of its impact upon the model.

Apple's model [Ref. 5] assumed that, once determined, the quantities of size Q_i and R_i would be bought and inducted for repairs, respectively, whenever necessary. It was also shown that the lowest SW values occurred when $Q_i = 1$ and $R_i = 1$. Gormly [Ref. 6: p. 32] acknowledged that this might not be possible if the annual UICP budgets designed to fund procurements and repairs were too low. Fortunately, with the advent of stock funding of depot level repairables, this is no longer a major concern.

At the present time, SPCC uses an R_i value of 1.0. Current policy dictates that carcasses are inducted for repair as soon as they are returned from the customer to the wholesale system. No carcasses are permitted to accumulate at the stock point. Economic repair quantities and shipping costs are no longer a critical consideration as it is recognized that repair turn-around time has previously been seriously affected by considering them. Depot workload scheduling by SPCC is based on expected carcass returns. Finally, depot workload scheduling and capacity is no longer a critical concern since it is felt that work can be easily and expeditiously redistributed.

Thus, the procurement of repairables has become the prime area of concern at the ICPs because of the associated amount of effort (workload) required to negotiate for a replenishment buy. They are making a conscious effort to minimize the number of procurements made annually. The question becomes not one of how often to buy, but how much to buy to minimize workload. It would seem that this would equate to buying the larger of the current economic order quantity (EOQ) or annual attrition demand. This, however, is not the only aspect of the ICP's procurement workload problem.

A review of wholesale stock levels has shown fluctuations in the requirements for those stock levels due to frequent and large changes in forecasted demand. This has often resulted in serious changes in the way items are managed. In particular, the demand probability distribution may change from one quarter to the next. This cyclic phenomenon, referred to as "churn" at the ICP level, is responsible for additional workload burden that could possibly be substantially reduced by procuring, as a minimum, the expected annual attrition demand.

2. MSRT Goal

An MSRT goal of 125 hours (CONUS) for the total supply system has been established by the Naval Supply Systems Command. The wholesale system's part of this goal is 13.05 days for items in stock [Ref. 8]. To date, no MSRT goals have been incorporated into ICP models. The use of 13.05 days in this analysis is a logical "first cut" for the aggregate demand repairables model. The trade-off between investment levels and the MSRT goal must eventually be considered. A first look at that trade-off will be presented in Chapter III where four MSRT goals are applied to 7H Cog data.

3. Reorder Points

The reorder points can be easily determined once Q and R have been established. The SW_i values calculated by this model represent the maximum values of the inventory position. As demands occur, the inventory position decreases. When a repair induction is made, the inventory position for item i is increased by the value of the expected successful regenerations (or R_i / RSR_i). When the inventory position immediately after a repair induction reaches or falls below the reorder point (SW_i - Q_i), a procurement should be made. This immediately returns the inventory position to SW_i.

III. MODEL PROGRAMMING AND ANALYSIS

In his testing of the aggregate demand replenishment model, Gormly utilized artificial data which was entered as a part of the program. To test the model with real data, three Computation and Research Evaluation System (CARES) worktapes of ASO and SPCC repairables items were obtained from FMSO in early 1986. Two of the tapes contained primarily 2R and 7H Cog items. The third tape contained 7G Cog along with an assortment of other Cogs. Tape size varied from over thirty thousand items for the 2R and 7H tapes to over one hundred fifty thousand on the 7G tape. Demands ranged from less than .25 to over 4,000 per quarter with unit prices ranging from less than one dollar to over ten thousand dollars.

The data from each CARES worktape was transferred to data sets on public storage disks at the Naval Postgraduate School Computer Center. Subsequent programming and analysis on the IBM 3033 located at the Postgraduate School referenced these data sets. Initial sorts of these data sets eliminated all but the primary Cog items (2R, 7H, 7G) and all but Mark IV items (high demand items, high demand value or high cost). This process is outlined in Appendix B.

A. REAL WORLD DATA

Additional sorts served to identify possible outliers. For example, a quarterly demand of 25,000 listed on the 2R Cog CARES worktape was subsequently discarded. Finally, a sort of the data sets was made to yield a sample size sufficiently large to validate the model program but small enough to ensure minimal computer storage and processing time. Ultimately, ten 7H Cog items, eleven 2R Cog items and fourteen 7G Cog items were selected.

ICP modifications to CARES data fields yielded some unacceptable results when variables were initially programmed using the assumed format. For example, the On Hand System Ready-For-Issue (data element number A012 of the CARES worktape) and On Hand System Not-Ready-For-Issue data fields listed as 8 digit integers were found to contain random characters in the eighth digit location. This precluded addition of these two fields to determine the present wholesale inventory levels.

While analysis of the entire Cog listings would have been the ultimate test of model and program validity, a sort on the quarterly demand field (data element number

B074 of the CARES worktape) was made to yield no more than fifteen items per tape for analysis. This provided a data output of workable size by Cog, served to further validate the aggregate demand repairables replenishment model program and established a workable program readily adaptable to future analysis.

B. REPROGRAMMING

The major part of reprogramming the aggregate demand replenishment model to accept real data involved the initial reading and sorting of the CARES worktapes. Modifications to Gormly's program (Appendix A) were also needed to facilitate wide ranges of parameter values. These included demands ranging from less than .25 per quarter to over four thousand per quarter. Finally, the inclusion of non-standard stock numbers in the CARES worktapes required manipulation of variables to overcome the existence of alpha-numeric characters and of NATO (01xxxxxxx) stock numbers in the national item identification number (NIIN) field.

WATF77, now in operation at the Naval Postgraduate School Computer Center, does not allow the degree of flexibility previously provided by WATFIV and thus does not readily accept an alpha-numeric NIIN or NATO stock number in array placement. This problem was circumvented by eliminating the NIIN within the program and assigning it an integer value. These are defined in Appendix S.

1. Model Changes

As this particular analysis of the model was designed to look at varying the procurement quantity between economic order quantity and annual attrition demand because of their effect on procurement workload, equations to compute those quantities, as is currently being done by the ICPs, were built into the model. Annual attrition demand is computed as:

$$(4 * D\,(1 - CRR * RSR)) = 4 * (D - REG) \qquad \text{(eqn 3.1)}$$

where:

D	=	Quarterly demand;
(CRR * RSR)	=	Regeneration rate and;
D * (CRR * RSR)	=	Quarterly regenerations, or REG.

REG, like D, is an ICP forecasted value and was read directly from the CARES worktape. The value (D - REG) is referred to as the attrition demand, or that quarterly demand which remains unfilled after a given number of NRFI carcasses are repaired and returned to the supply system (regenerations) as RFI assets.

The unconstrained economic order quantity (EOQ) is computed as:

SQRT ((8 * (D - REG) * A1) / (HCR * C1)) (eqn 3.2)

where:

A1 = a constant large purchase procurement cost value established by the ICP;

HCR = the annual holding cost rate. (.21 currently assigned for repairables)

C1 = Unit price (procurement)

Additionally, recognizing that limited instances may exist in which EOQ will exceed annual demand for the high demand items analyzed, a third option allowing for a choice of the higher of the two quantities has been added. This will allow further analysis of procurement quantities when looking at items with lower demand. This situation did not occur in this analysis. These Q values are programmed in Appendices C through F.

C. MODEL RESULTS

Table 1 provides a brief explanation of the column headings found in the tables and appendices that follow.

Appendices G through O provide the results of computer runs for 2R, 7H, and 7G Cog items when the MSRT goal is 13.05 days and the procurement quantities are the EOQ, the annual attrition demand and one unit. In all cases, the repair induction quantity is 1.0, and the carcass return time (CRT) has been arbitrarily assigned a constant value of 1.86 quarters based on discussions with ICP personnel. Because of the sorting according to marginal analysis weights which is a part of the computer program, the item order appears different in each table.

Appendices G, H and I show the SWR values for eleven 2R Cog items when economic order quantity, average annual attrition demand, and 1.0, respectively, are the values of Q. These are summarized in Table 2.

TABLE 1

EXPLANATION OF COLUMN HEADINGS

CMSRT	Computed Mean Supply Response Time
MSRT	Mean Supply Response Time Goal
NUM	Item Number
QP	Procurement Quantity (average annual attrition demand,EOQ, or unity)
C2	Repair Cost, dollars
RSR	Repair Survival Rate
RTAT	Repair Turn-Around Time, quarters
PCLT	Procurement Lead Time, quarters
D	Quarterly Demand
MU	Mean number of units in resupply (See Equations 2.6 and 2.7)
PPV	Procurement Problem Variable
CTWUS1	Computed Time Weighted Units Short
SWR	Wholesale Stock Level
COST C1	Unit price (procurement),dollars
COSTSW	Investment Level For One Line Item when the Wholesale Level is SW

TABLE 2

SUMMARY OF 2R COG SWR RESULTS FOR MSRT = 13.05 DAYS

				SWR	
NUM	PPV	C1	Q = 1.0	Q = EOQ	Q = ATT DEM
1	1911.4189	136.00	1735	1814	1922
2	2968.7834	310.00	2345	2419	2701
3	3704.3564	111.00	3425	3640	4461
4	10956.2734	103.00	10186	10544	12936
5	2936.8064	101.00	2782	2949	3353
6	3153.0510	181.00	2766	2908	3529
7	4457.7617	257.00	3500	3660	4890
8	2660.5293	60.00	2552	2810	3352
9	1893.3428	162.00	1760	1783	1788
10	2528.6372	284.00	2000	2111	2769
11	4567.0078	322.00	4084	4163	4474

These represent 2R items, less outliers, with quarterly demands in excess of 600 units. Unit prices, C1, range from \$60 to \$322. The column designated PPV presents the values of the procurement problem variable or mean demand during the repairables

cycle (see Equation 2.7). These values are the the lower bound on the current ICP reorder point values. The total investment level when Q equals the average annual attrition demand is S7,878,213. This is reduced by approximately sixteen percent (to S6,648,939) when Q is equal to the EOQ. When Q was equal to 1.0, the investment level drops to S6,394,459.

Appendices J, K and L list the outputs when Q is the economic order quantity, the average annual attrition demand, and 1.0, respectively, for ten 7H Cog items. These items were those having quarterly demands in excess of 150 units. (Temporary Navy Item Control Numbers (T-NICNs) with identical NIIN entries were deleted). The results are summarized in Table 3.

TABLE 3

SUMMARY OF 7H COG SWR RESULTS
MSRT GOAL = 13.05 DAYS

				SWR	
NUM	PPV	CI	Q = 1.0	Q = EOQ	Q = ATT DEM
1	19422.7266	12930.00	17599	17641	22054
2	963.7781	959.00	961	1001	1268
3	966.0208	1170.00	979	992	1026
4	951.0232	959.00	949	988	1249
5	2267.1213	247.00	2324	2377	2463
6	2807.1431	1150.00	2800	2856	3531
7	1715.4697	590.00	1754	1769	1785
8	1375.3096	1160.00	1384	1407	1508
9	623.4763	1280.00	633	641	652
10	927.3884	1420.00	946	954	971

A twenty percent reduction (S298,456,320 to S239,888,672) in total investment level is realized when Q is reduced from annual attrition demand to the EOQ. When Q is equal to 1.0, the investment level drops to S239,120,000.

Appendices M, N and O show similar results for 7G Cog items which are summarized in Table 4.

These fourteen 7G Cog items had a quarterly demand exceeding 175 units. Approximately a five percent reduction (S33,237,344 to S31,693,264) in total investment level is achieved when procuring the EOQ vice the annual attrition demand. When Q is equal to 1.0, the investment level drops to S31,433,808. For three items, the

TABLE 4

SUMMARY OF 7G COG SWR RESULTS
MSRT GOAL = 13.05 DAYS

			SWR		
NUM	PPV	C1	Q = 1.0	Q = EOQ	Q = ATT DEM
1	1453.8762	6730.00	1042	1050	1136
2	1317.3320	1050.00	1245	1282	1542
3	388.6873	838.00	374	374	375
4	287.9741	1880.00	260	260	261
5	263.5120	1890.00	238	238	239
6	737.5679	886.00	691	700	707
7	615.5908	1340.00	559	575	635
8	834.8708	375.00	800	806	808
9	781.7603	1610.00	713	722	742
10	1117.1565	1140.00	1020	1031	1054
11	2476.6921	2470.00	2324	2334	2378
12	596.8831	1970.00	545	552	570
13	3785.1675	990.00	3704	3730	3842
14	3552.4468	2150.00	3260	3279	3412

procurement quantity is zero for the first two procurement quantities. This is a consequence of those items having an excess in forecasted regenerations when compared to forecasted demands.

D. MSRT IMPACT ON WHOLESALE INVESTMENT LEVELS

As the mean supply response time is a critical parameter of this analysis, it is important to look at the trade-off between MSRT and wholesale investment levels. To accomplish this, total investment levels have been computed for the 7H Cog items using Q equal to the annual attrition demand and additional MSRT goal values of one day, seven days, and twenty one days. The results of this analysis are detailed in Appendices P, Q, and R. Table 5 and Figure 3.1 show the results for the four MSRT goal values.

Overall, an 8.5 percent reduction in total investment level is attained when increasing the MSRT goal from 1 day to 21 days when Q is the annual attrition demand. The reduction from 13.05 days to 21 days is 2.5 percent.

As PPV currently serves as a reorder point lower bound for the ICPs, it is of interest to compare the new reorder point values (SWR - Q) with PPV as the MSRT goal changes.

TABLE 5
INVESTMENT LEVELS FOR FOUR MSRT GOALS

MSRT Goal (Days)	Investment Level (Dollars)
1	$318,060,800
7	$305,639,168
13.05	$298,456,320
21	$291,273,984

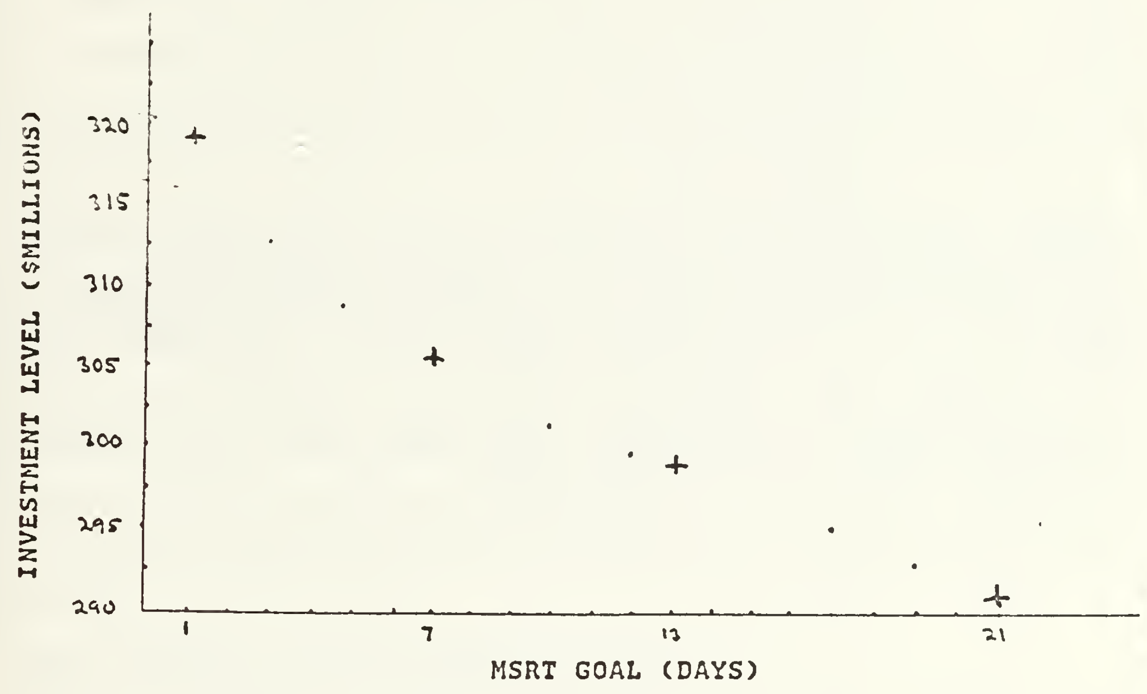


Figure 3.1 MSRT Versus Total Investment Level.

Table 6 shows the correlation between the two values when Q is equal to the annual attrition demand. The reorder point lower bound (SW - Q) value approaches PPV as the MSRT goal is decreased from 21 days to 1 day. Only one case (item

TABLE 6

COMPARISON OF (SWR - Q) TO PPV AS MSRT GOAL CHANGES

ITEM	PPV	ROP = SWR - Q			
		MSRT = 1	MSRT = 7	MSRT = 13.05	MSRT = 21
1	19422.7266	14223.36	13277.36	12727.36	12177.36
2	963.7781	684.08	661.08	652.08	643.08
3	966.0208	959.48	942.48	936.48	929.48
4	951.0232	677.24	654.24	645.24	637.24
5	2267.1213	2219.28	2200.28	2193.28	2186.28
6	2807.1431	2122.04	2082.04	2067.04	2052.04
7	1715.4697	1754.12	1736.12	1729.12	1722.12
8	1375.3096	1294.76	1272.96	1264.76	1256.76
9	623.4763	635.28	622.28	616.28	612.28
10	927.3884	946.48	930.48	925.48	919.48

number 7) occurs in which the reorder point lower bound exceeds the PPV for all MSRT goals. Items 1, 2, 4, and 6 show a significant difference between the SW - Q value and the PPV. These items are characterized by extremely low carcass return rates.

To obtain new reorder point values larger than PPV, it is obvious that an MSRT goal smaller than 1 day will be needed.

IV. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

Chapter II provided a cursory review of the repairables system as an introduction to a discussion of Gormly's thesis [Ref. 6]. Gormly's model, like Apple's [Ref. 5] before his, is a performance and a Navy oriented multi-echelon model. Whereas Apple's model had used mean supply response time (MSRT) as an objective function, the objective of Gormly's model was to minimize the wholesale stock level investment while attempting to achieve an established goal. The purpose of both was to address both the issues of readiness (MSRT) and the Navy's concern over investment levels. Gormly's model was selected as the basis for the model analyzed in this thesis. Chapter II additionally discussed the role which the procurement quantity currently plays in the determination of the procurement workload scheduling at the ICP. Three different procurement quantities were proposed for analysis: one unit, the current ICP economic order quantity, and the value of the annual attrition demand.

Chapter III discussed the nature of the real data obtained from SPCC and ASO and the programming modifications necessary to adapt the aggregate demand model program to utilize that data. The data selected for the analysis consisted of eleven 2R Cog items, ten 7H Cog items and fourteen 7G Cog items. These represented the fastest movers in each of these major Cogs. It also discussed the MSRTs and total investment levels which were computed when running the model program with 2R, 7H, and 7G Cog data and illustrated the relationship between the MSRT goal and the total investment level.

B. CONCLUSIONS AND RECOMMENDATIONS

Results of this limited analysis demonstrate one key point. Increasing the procurement quantity to reduce workload or increasing it to meet the current reorder point lower bound results in significant increases in investment levels over those which are optimum (i.e., those associated with Q = 1.) in absence of workload constraints. The cost of this investment must be weighed against the savings in workload for an objective decision to be made concerning the size and freqency of procurements.

A second issue is what is a reasonable MSRT goal? Again, a trade-off exists between MSRT and the investment levels. The answer to this question is not obvious and will require much future study.

As the current effort was primarily involved with making modifications to the computer program developed by Gormly to make it compatible with real-world data input, further analysis of the model with real data remains a rich area. First, since this model looked at only a small quantity of highdemand items, research should expand the analysis to look at the full range of items in the 2R, 7H and 7G Cogs. This would include not only high-demand items but low-demand items as well. This would serve to validate the use of the Poisson distribution as well as complete the overall performance evaluation of the aggregate demand model. These future analyses should continue to investigate variations in the procurement quantity to complete the picture of the procurement workload's impact on investment levels.

This study, as Gormly's before it, followed the current ICP approach and assumed a separation of all items into IMEC categories and assignment of appropriate MSRT goals for each level. Subsequently, a single MSRT goal was used for the fast moving items analyzed. An area of follow-on study is recommended which would assign different MSRT goals based on the IMEC codes assigned by the ICP.

Finally, the structure of the aggregate demand model when the forecasted quarterly regenerations exceed the forecasted quarterly demand needs to be investigated. The current form of the model assumes regenerations do not exceed demand.

APPENDIX A

COMPUTER PROGRAM LISTING - GORMLY'S MODEL

```
$JOB
C
C
C        **** VARIABLES  DESCRIPTION ****
C
C     ARR    :  ARRAY STORAGE
C     ATT    :  ATTRITION RATE (NUMBER OF UNITS)
C     CMSRT  :  COMPUTED MEAN SUPPLY RESPONSE TIME
C     COSTSW:   EXTENDED COST, OPTIMUM WHOLESALE STOCK LEVEL (C1*SWR)
C     CRR    :  CARCASS RETURN RATE(PROBABILITY)
C     CRT    :  CARCASS RETURN TIME
C     CTWUS1:   COMPUTED TIME WEIGHTED UNIT SHORT FOR SW
C     CTWUS2:   COMPUTED TIME WEIGHTED UNIT SHORT FOR SW + 1
C     C1     :  PROCUREMENT COST PER UNIT
C     C2     :  REPAIR COST PER UNIT
C     D      :  DEMAND FOR AN ITEM
C     I      :  INDEX VARIABLE
C     INVEST:   MINIMUM REQUIRED INVESTMENT
C     J      :  INDEX VARIABLE
C     JJ     :  INDEX VARIABLE
C     K      :  INDEX VARIABLE
C     L      :  INDEX VARIABLE
C     LL     :  INDEX VARIABLE
C     N      :  INDEX VARIABLE
C     NN     :  INDEX VARIABLE
C     MSRT   :  MEAN SUPPLY RESPONSE TIME GOAL
C     MU     :  TOTAL PROGRAM PROBLEM VARIABLE
C     MUP    :  PROCUREMENT PROBLEM VARIABLE
C     MUR    :  REPAIR PROBLEM VARIABLE
C     NIIN   :  NATIONAL ITEM IDENTIFICATION NUMBER
C     PCLT   :  PROCUREMENT CYCLE LEAD TIME
C     Q      :  PROCUREMENT LOT SIZE
C     R      :  REPAIR BATCH SIZE
C     REG    :  REGENERATION RATE (NUMBER UNITS)
C     RSR    :  REPAIR SURVIVAL RATE (PROBABILITY)
C     RTAT   :  REPAIR TURN-AROUND TIME
C     S      :  TEMPORARY STORAGE
C     S1     :  TEMPORARY STORAGE
C     S2     :  TEMPORARY STORAGE
C     S3     :  TEMPORARY STORAGE
C     S4-S10:   TEMPORARY STORAGE
C     SW     :  WHOLESALE SYSTEM STOCK LEVEL
C     SWR    :  FINAL WHOLESALE SYSTEM STOCK LEVEL
C     TWUS   :  TIME WEIGHTED UNITS SHORT
C     TT1    :  MEAN LENGTH OF REPAIR CYCLE
C     TT2    :  MEAN LENGTH OF PROCUREMENT CYCLE
C     WT     :  COMPUTED WEIGHT FOR MARGINAL ANALYSIS
C
C         **** VARIABLE DECLARATION ****
C
       REAL ATT(2),REG(2),C1(2),C2(2),MU(2),Q(2),R(2),
      *MUP(2),MUR(2),RSR(2),CRR(2),CRT(2),RTAT(2),PCLT(2),D(2),
      *WT(2),INVEST,MSRT,CMSRT,ARR(2,10),S,
      *CTWUS1(2),CTWUS2(2),COSTSW(2)
C
       INTEGER NIIN(2),S1,S2,S3,SW(2),SWR(2)
C
       N=2
C
     1 CALL READA (N,MSRT,NIIN,ARR,ATT,REG,C1,C2,RSR,
      *CRR,CRT,RTAT,PCLT,D,Q,R)
```

```
C
 5000 CALL COMPMU (N,RSR,CRR,CRT,RTAT,R,D,PCLT,Q,MU,MUP,MUR,NIIN)
C
       DO 6000 I=1,N
          SW(I)=0
C
 6000 CONTINUE
C
 7000 CALL CPTWUS (N,SW,CTWUS1,CTWUS2,MU,P,C,MSRT,CMSRT,SWR,
     *WT,ARR,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,Q,R)
C
 8000 CALL MINVST (N,INVEST,C1,SWR,COSTSW)
C
 9000 CALL WRITER (CMSRT,MSRT,N,NIIN,ARR,MU,CTWUS1,WT,SWR,C1,
     *COSTSW,INVEST,Q,R)
C
 9999 STOP
       END
C
C     *****ROUTINE TO READ IN INITIAL DATA*****
C
 0001 SUBROUTINE READA (N,MSRT,NIIN,ARR,ATT,REG,C1,C2,RSR,
     *CRR,CRT,RTAT,PCLT,D,Q,R)
C
       INTEGER N,NIIN(N)
C
       REAL MSRT,ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),
     *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),Q(N),R(N)
C
       READ (5,900) N,MSRT
C
       DO 10 I=1,N
          READ (5,910) NIIN(I),(ARR(I,J),J=1,10),Q(I),R(I)
C
   10 CONTINUE
C
       CALL ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
  900 FORMAT (I3,3X,F8.5)
  910 FORMAT (2X,I9,1X,4F10.2,2(F6.4,1X),F5.2,1X,F6.3/2X,F6.3,2X,
     *F7.3,2(2X,F5.2))
       RETURN
       END
C
C*** ROUTINE TO REARRANGE ARRAY ASSIGNMENTS *******
C
  601 SUBROUTINE ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
       INTEGER N
C
       REAL ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),
     *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N)
C
       DO 600 I=1,N
          ATT(I)=ARR(I,1)
          REG(I)=ARR(I,2)
          C1(I) =ARR(I,3)
          C2(I) =ARR(I,4)
          RSR(I)=ARR(I,5)
          CRR(I)=ARR(I,6)
          CRT(I)=ARR(I,7)
          RTAT(I)=ARR(I,8)
          PCLT(I)=ARR(I,9)
          D(I)=ARR(I,10)
C
  600 CONTINUE
       RETURN
       END
C
```

```
C     *****ROUTINE TO COMPUTE MUP,MUR,MU*****
C
 5001 SUBROUTINE COMPMU (N,RSR,CRR,CRT,RTAT,R,D,PCLT,Q,MU,MUP,MUR,
     *NIIN)
C
      INTEGER N,NIIN(N)
C
      REAL RSR(N),CRR(N),CRT(N),RTAT(N),D(N),PCLT(N),Q(N),R(N),
     *MU(N),MUR(N),MUP(N)
C
      DO 5310 I=1,N
         MUR(I)=(RSR(I)*CRR(I))*(CRT(I)+RTAT(I)+((R(I)-1.)/
C
     *   (2.*D(I)*RSR(I)*CRR(I))))
C
         MUP(I)=(1.-(RSR(I)*CRR(I)))*(PCLT(I)+((Q(I)-1.))/
     *   (2.*D(I)*(1.-(RSR(I)*CRR(I)))))
C
         MU(I)=(D(I)*(MUR(I)+MUP(I)))
C
 5310 CONTINUE
      RETURN
      END
C
C     **** ROUTINE TO COMPUTE TIME WEIGHTED UNIT SHORT FOR SW ****
C
 7001 SUBROUTINE CPTWUS (N,SW,CTWUS1,CTWUS2,MU,P,C,MSRT,CMSRT,SWR,
     *WT,ARR,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,Q,R)
C
      INTEGER N,SW(N),K,NIIN(N),SWR(N)
C
      REAL CTWUS1(N),CTWUS2(N),MU(N),P,C,MSRT,WT(N),ARR(N,10),ATT(N),
     *REG(N),C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),
     *CMSRT,Q(N),R(N)
C
      CALL CTWSW0 (N,SW,CTWUS1,MU,P,C,CMSRT,MSRT,SWR,D,PCLT)
C
      IF (CMSRT.LE.MSRT) GO TO 7090
      J=1
C
 7005 DO 7080 I=1,N
C
         IF (J.EQ.1) GO TO 7050
         K=SW(I)+ J- 1
         SWR(I)=K
         Z=MU(I)
         IF (Z.GE.20.) GO TO 7010
C
         CALL CDFP (Z,K,P,C)
C
         CTWUS1(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *   (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
C
         GO TO 7020
C
 7010    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
         CTWUS1(I)=CTWUS
C
 7020    CALL CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
C
         WRITE (6,9999) CMSRT,MSRT,CTWUS1(I),SWR(I),NIIN(I)
C
 9999    FORMAT (/2X,'CMSRT:',F10.4,2X,'MSRT:',F10.4,2X,'CTWUS1:',
C    *   F10.4,2X,'SW:',I4,2X,'NIIN:',I9)
C
         IF (CMSRT.LE.MSRT) GO TO 7090
C
C     **** COMPUTE TIME WEIGHTED UNITS SHORT FOR SW + 1 ****
C
```

```
 7050    Z=MU(I)
           K=SWR(I)+1
           IF (Z.GE.20.) GO TO 7060
C
           CALL CDFP (Z,K,P,C)
C
           CTWUS2(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *    (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
C
           IF(J.EQ.1.AND.I.NE.N) GO TO 7080
C
           GO TO 7070
C
 7060    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
           CTWUS2(I)=CTWUS
           IF(J.EQ.1.AND.I.NE.N) GO TO 7080
C
 7070    MM=NIIN(I)
           CALL CPWTS (WT,CTWUS1,CTWUS2,SWR,ARR,N,NIIN,ATT,REG,
     *    C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,MU,Q,R)
           IF (MM.NE.NIIN(I)) GO TO 7075
           GO TO 7085
C
 7075    J=SWR(I)+1
           GO TO 7085
C
 7080 CONTINUE
C
 7085 J=J+1
        I=1
        GO TO 7005
 7090 RETURN
        END
C
C*****ROUTINE TO COMPUTE TWUS WITH SW=0*****
C
 7100 SUBROUTINE CTWSW0 (N,SW,CTWUS1,MU,P,C,CMSRT,MSRT,SWR,D,PCLT)
C
        INTEGER N,SW(N),K,SWR(N)
C
        REAL CTWUS1(N),MU(N),P,C,MSRT,Z,D(N),PCLT(N),CMSRT
C
        DO 7130 I=1,N
           K=SW(I)
           SWR(I)=K
           Z=MU(I)
           IF (Z.GE.20.) GO TO 7110
C
           CALL CDFP (Z,K,P,C)
C
           CTWUS1(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *    (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))

           GO TO 7120
C
 7110    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
           CTWUS1(I)=CTWUS
C
 7120    IF (I.NE.N) GO TO 7130
           CALL CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
C
 7130 CONTINUE
        RETURN
        END
C
C     *****ROUTINE TO COMPUTE POISSON PROBABILITIES*****
C
 7200 SUBROUTINE CDFP (Z,K,P,C)
C
```

```
      REAL  ZZZ,PP,CC
      REAL Z,P,C
      INTEGER K,J
      ZZZ=Z
      PP=EXP(-ZZZ)
      CC=PP
      IF (K.EQ.0) GO TO 7220
c
      DO 7210 J=1,K
         PP=PP*ZZZ/DFLOAT(J)
         CC=CC+PP
c
 7210 CONTINUE
 7220 P=PP
      C=CC
      RETURN
      END
C
C    *****ROUTINE TO CALCULATE NORMAL PROBABILITIES AND TWUS*****
C
 7300 SUBROUTINE NORMAL (Z,K,I,PCLT,CTWUS,N)
c
      INTEGER K,I,N
c
      REAL S,Z,T1,T2,CA,CB,PCLT(N)
c
      S=FLOAT(K) + 0.5
      T1=(S-Z)/SQRT(Z)
      T2=(S-Z-1.0)/SQRT(Z)
c
      CALL MDNOR (T1,CA)
      CALL MDNOR (T2,CB)
c
      CTWUS=(PCLT(I)/2.)*(CA*(K-(K*(K+1)/Z))-CB*(Z-K)+
     *(Z-2.*K+K*(K+1)/Z))
      RETURN
      END
C
C  **** ROUTINE TO COMPUTE MSRT AND COMPARE TO MSRT GOAL ****
C
 7400 SUBROUTINE CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
c
      INTEGER N
c
      REAL CMSRT,D(N),CTWUS1(N),MSRT,CCTWUS,DD
c
      CCTWUS=0.0
      DD=0.0
c
      DO 7410 I=1,N
         X=CTWUS1(I)
         IF(CTWUS1(I).LT.0) X=0.
         CCTWUS=CCTWUS + X
         DD=DD+D(I)
c
 7410 CONTINUE
      CMSRT=CCTWUS/DD
c
      RETURN
      END
C
C     **** ROUTINE TO COMPUTE WEIGHTS AND FIND SMALLEST ****
C
 7500 SUBROUTINE CPWTS (WT,CTWUS1,CTWUS2,SWR,ARR,N,NIIN,
     *ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,MU,Q,R)
c
      INTEGER N,SWR(N),NIIN(N)
c
      REAL WT(N),CTWUS1(N),CTWUS2(N),ARR(N,10),ATT(N),REG(N),Q(N),
```

```
     *C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),MU(N),R(N)
C
      DO 7510 I=1,N
          WT(I)=C1(I)/(CTWUS1(I)-CTWUS2(I))
C
 7510 CONTINUE
C
      CALL SORTS (ARR,N,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,
     *PCLT,D,WT,SWR,MU,CTWUS1,CTWUS2,Q,R)
C
      RETURN
      END
C
C     *****ROUTINE TO SORT FROM SMALLEST TO LARGEST*****
C
 7600 SUBROUTINE SORTS (ARR,N,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,
     *RTAT,PCLT,D,WT,SWR,MU,CTWUS1,CTWUS2,Q,R)
C
      INTEGER N,NIIN(N),S1,S4,SWR(N)
C
      REAL ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),CRR(N),CRT(N),
     *RTAT(N),PCLT(N),D(N),WT(N),MU(N),CTWUS1(N),CTWUS2(N),Q(N),R(N)
C
      NN=N-1
C
      DO 7630 J=1,NN
          L=J
          JJ=J+1
C
          DO 7610 K=JJ,N
              IF (WT(L).LT.WT(K)) GO TO 7610
              L=K
 7610     CONTINUE
C
          DO 7620 M=1,10
              S=ARR(L,M)
              ARR(L,M)=ARR(J,M)
              ARR(J,M)=S
C
 7620     CONTINUE
C
          CALL ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
          S1=NIIN(L)
          NIIN(L)=NIIN(J)
          NIIN(J)=S1
          S4=SWR(L)
          SWR(L)=SWR(J)
          SWR(J)=S4
          S5=MU(L)
          MU(L)=MU(J)
          MU(J)=S5
          S6=WT(L)
          WT(L)=WT(J)
          WT(J)=S6
          S7=CTWUS1(L)
          CTWUS1(L)=CTWUS1(J)
          CTWUS1(J)=S7
          S8=CTWUS2(L)
          CTWUS2(L)=CTWUS2(J)
          CTWUS2(J)=S8
          S9=Q(L)
          Q(L)=Q(J)
          Q(J)=S9
          S10=R(L)
          R(L)=R(J)
          R(J)=S10
C
 7630 CONTINUE
      RETURN
```

```
      END
C
C     *****ROUTINE TO COMPUTE MINIMUM INTITIAL INVESTMENT*****
C
 8001 SUBROUTINE MINVST (N,INVEST,C1,SWR,COSTSW)
c
      INTEGER N,SWR(N)
c
      REAL INVEST,C1(N),COSTSW(N)
c
      INVEST=0.0
      DO 8650 I=1,N
         COSTSW(I)=C1(I)*SWR(I)
         INVEST=INVEST+COSTSW(I)
c
 8650 CONTINUE
      RETURN
      END
C
C     *****ROUTINE TO WRITE ALL DATA*****
C
 9001 SUBROUTINE WRITER(CMSRT,MSRT,
     *N,NIIN,ARR,MU,CTWUS1,WT,SWR,C1,COSTSW,INVEST,Q,R)
c
      INTEGER N,NIIN(N),SWR(N)
c
      REAL CMSRT,MSRT,ARR(N,10),
     *MU(N),CTWUS1(N),WT(N),C1(N),COSTSW(N),INVEST,Q(N),R(N)
c
      WRITE (6,9020)
      WRITE (6,9107)
c
      DO 9120 I=1,N
c
         WRITE (6,9108) NIIN(I),Q(I),R(I)
c
 9120 CONTINUE
c
      WRITE (6,9020)
c
      CMSRT=CMSRT*91.
      MSRT=MSRT*91.
c
 9740 WRITE (6,9741) CMSRT,MSRT
      WRITE (6,9020)
c
 9760 WRITE (6,9761)
      DO 9762 I=1,N
c
         WRITE (6,9763) NIIN(I),(ARR(I,J),J=1,10),MU(I),CTWUS1(I),
     *   WT(I),SWR(I)
c
 9762 CONTINUE
      WRITE (6,9020)
c
 9800 WRITE (6,9890)
      DO 9810 I=1,N
c
         WRITE (6,9896) NIIN(I),SWR(I),C1(I),COSTSW(I)
c
 9810 CONTINUE
      WRITE (6,9010)
      WRITE (6,9898) INVEST
c
 9010 FORMAT (//)
 9020 FORMAT (     )
 9107 FORMAT (5X,'NIIN',10X,'Q',13X,'R')
 9108 FORMAT (/2X,I9,3X,F10.2,3X,F10.2)
 9741 FORMAT (/'+++++++++CMSRT:',F10.4,1X,'DAYS',3X,'MSRT:',F10.4,1X,
```

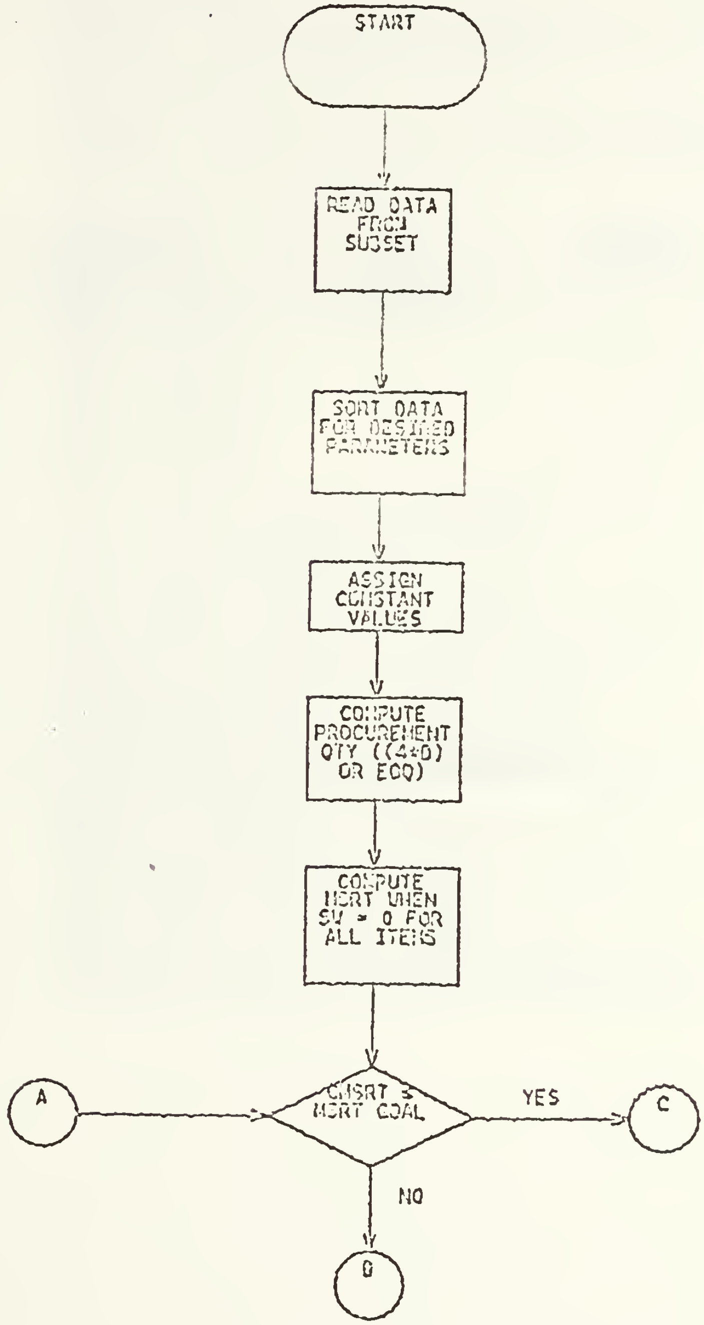
```
      *'DAYS','+++++++++++')
C
 9761 FORMAT (/5X,'NIIN',9X,'ATT',7X,'REG',5X,'C1',8X,'C2',6X,
     *'RSR',4X,'CRR',4X,'CRT',3X,'RTAT',3X,'PCLT',5X,'D',10X,'MU',7X,
     *'CTWUS1',6X,'WT',6X,'SWR')
C
 9763 FORMAT (/2X,I9,1X,4F10.2,1X,2(F6.4,1X),F5.2,1X,F6.3,1X,F6.3,
     *1X,F7.3,1X,2(F10.4,1X),E11.4,1X,I4)
C
 9890 FORMAT (5X,'NIIN',5X,'SWR',5X,'COST C1',8X,'COSTSW')
 9896 FORMAT ( 2X,I9,3X,I3,3X,F10.2,3X,F14.2)
 9898 FORMAT (////2X,'********** TOTAL MINIMUM INITIAL INVESTMENT:$',
     *F14.2,2X,'TOTAL MINIMUM INITIAL INVESTMENT **********')
C
       RETURN
       END
$ENTRY
```

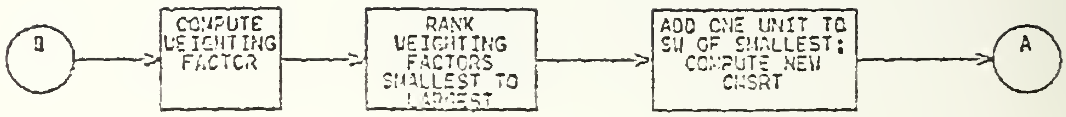
Test Data

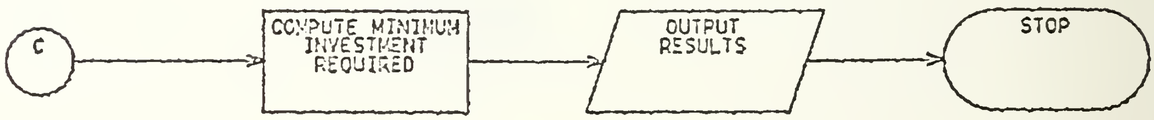
```
 N       MSRT
 2    000.0572

   NIIN              ATT        REG        C1           C2       RSR       CRR      CRT    RTAT
 222222222           .36        8.24   10000.00      5000.00  .9850     .9725     .75    1.990

    PCLT        D         Q        R
  7.140     8.600     1.00     6.00

   NIIN              ATT        REG        C1           C2       RSR       CRR      CRT    RTAT

 666666666           .36        8.24  150000.00    75000.00  .9850     .9725     .75    1.990

  PCLT        D         Q        R
  7.140     8.600     1.00     1.00
```

APPENDIX B

FLOW CHART OF AGGREGATE DEMAND REPAIRABLES REPLENISHMENT MODEL




B
COMPUTE WEIGHTING FACTOR
RANK WEIGHTING FACTORS SMALLEST TO
ADD ONE UNIT TO SW OF SMALLEST; COMPUTE NEW CNSRT
A


C
COMPUTE MINIMUM INVESTMENT REQUIRED
OUTPUT RESULTS
STOP

APPENDIX C

VARIABLES LISTING FOR APPENDICES D, E, AND F

A1	:	PROCUREMENT COST
ARR	:	ARRAY STORAGE
ATT	:	ATTRITION RATE (NUMBER OF UNITS)
CMSRT	:	COMPUTED MEAN SUPPLY RESPONSE TIME
COSTSW	:	EXTENDED COST OF OPTIMUM WHOLESALE STOCK LEVEL (C1*SWR)
CRR	:	CARCASS RETURN RATE(PROBABILITY)
CRT	:	CARCASS RETURN TIME
CTWUS1	:	COMPUTED TIME WEIGHTED UNIT SHORT FOR SW
CTWUS2	:	COMPUTED TIME WEIGHTED UNIT SHORT FOR SW + 1
C1	:	PROCUREMENT COST PER UNIT
C2	:	REPAIR COST PER UNIT
D	:	QUARTERLY DEMAND FOR AN ITEM
HCR	:	HOLDING COST RATE
I	:	INDEX VARIABLE
INVEST	:	MINIMUM REQUIRED INVESTMENT
J	:	INDEX VARIABLE
JJ	:	INDEX VARIABLE
K	:	INDEX VARIABLE
L	:	INDEX VARIABLE
LL	:	INDEX VARIABLE
N	:	INDEX VARIABLE
NN	:	INDEX VARIABLE
MSRT	:	MEAN SUPPLY RESPONSE TIME GOAL
MU	:	TOTAL PROGRAM PROBLEM VARIABLE
MUP	:	PROCUREMENT PROBLEM VARIABLE
MUR	:	REPAIR PROBLEM VARIABLE
NUM	:	ITEM NUMBER (RELATES TO NIIN)
PCLT	:	PROCUREMENT CYCLE LEAD TIME
QPE	:	TEMPORARY QP VALUE - EOQ
QPA	:	TEMPORARY QP VALUE - ANNUAL DEMAND
QP	:	PROCUREMENT QUANTITY
R	:	REPAIR BATCH SIZE
REG	:	REGENERATION RATE (NUMBER UNITS)
RSR	:	REPAIR SURVIVAL RATE (PROBABILITY)
RTAT	:	REPAIR TURN-AROUND TIME
S1-S18	:	TEMPORARY STORAGE
SW	:	WHOLESALE SYSTEM STOCK LEVEL
SWR	:	FINAL WHOLESALE SYSTEM STOCK LEVEL
TWUS	:	TIME WEIGHTED UNITS SHORT
TT1	:	MEAN LENGTH OF REPAIR CYCLE
TT2	:	MEAN LENGTH OF PROCUREMENT CYCLE
WT	:	COMPUTED WEIGHT FOR MARGINAL ANALYSIS
Z	:	PROCUREMENT PROBLEM VARIABLE (OR MU WHEN R = 1)

APPENDIX D

COMPUTER PROGRAM LISTING FOR PROCUREMENT QUANTITY = ATT. DEMAND

```
C          **** VARIABLE DECLARATION ****
C
       REAL REG1,C1(50),C2(50),MU(50),QP(50),R,MUP(50),MUR(50),RSR(50),
      *CRR(50),CRT(50),RTAT(50),PCLT(50),D(50),WT(50),INVEST,MSRT,
      *CMSRT,ARR(50,10),S,CTWUS1(50),CTWUS2(50),COSTSW(50),S5,S6,S7,
      *S8,S9,S10,S11,S12,S13,S14,S15,S16,S17,S18,CTWUS,ATT
C
       INTEGER S1,S2,S3,SW(50),SWR(50),S4,CG,NUM(50)
C
         N = 0
         I = 1
         II = 0
C
 1     READ (30,30,END=600) CG,PCLT1,RSR1,RTAT1,C11,D1,REG1,C21
C
  30  FORMAT(I1,29X,F4.2,F3.2,F4.2,14X,F10.2,F10.2,F10.2,121X,F10.2,39X)
C
       IF (D1.LT.      ) GO TO 1
        A1 = 1100.00
        HCR = .21
        R = 1.
        MSRT = (87.* (.15))/91.
        CRT1 = (170./365.) * 4.
        CRR1 = REG1/(D1*RSR1)
C
         ATT = D1 - REG1
         IF (ATT.LT.0) GO TO 5
         QP1 = 4*(ATT)
         GOTO 6
  5     QP1 = 0
C
  6    II = II + 1
        N = N + 1
        NUM(N) = II
        QP(N)    = QP1
        PCLT(N) = PCLT1
        RSR(N)   = RSR1
        CRR(N)   = CRR1
        CRT(N)   = CRT1
        RTAT(N)   = RTAT1
        C1(N)    = C11
        D(N)     = D1
        C2(N)    = C21
C
        GO TO 1
C
 600   CALL ARRAYS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
 5000  CALL COMPMU (NUM,QP,C1,RSR,CRR,CRT,RTAT,PCLT,D,N,R,MUR,MUP,MU,
      *HCR,A1)
C
        DO 6000 I=1,N
        SW(I) = 0
C
 6000  CONTINUE
C
 7000 CALL CPTWUS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N,
      *R,MU,SW,CTWUS1,CTWUS2,P,C,MSRT,CMSRT,SWR,WT)
C
 8000 CALL MINVST (C1,N,SWR,COSTSW,INVEST)
```

```
C
 9000 CALL WRITER (ARR,NUM,QP,C1,N,R,MU,CTWUS1,MSRT,CMSRT,SWR,WT,
     *COSTSW,INVEST,D)
C
99999  STOP
        END
C
C  *****************************************************************
C                   END OF MAIN PROGRAM
C  *****************************************************************
C
C*** ROUTINE TO REARRANGE ARRAY ASSIGNMENTS *******
C
  601 SUBROUTINE ARRAYS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
       INTEGER N,NUM(N)
C
       REAL ARR(N,10),QP(N),C1(N),C2(N),RSR(N),
      *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N)
C
       DO 605 I = 1,N
          ARR(I,1) = NUM(I)
          ARR(I,2) = QP(I)
          ARR(I,3) = C1(I)
          ARR(I,4) = C2(I)
          ARR(I,5) = RSR(I)
          ARR(I,6) = CRR(I)
          ARR(I,7) = CRT(I)
          ARR(I,8) = RTAT(I)
          ARR(I,9) = PCLT(I)
          ARR(I,10) = D(I)
C
 605   CONTINUE
       RETURN
       END
C
C     **** ROUTINE TO COMPUTE MU ****
C
 5001  SUBROUTINE COMPMU (NUM,QP,C1,RSR,CRR,CRT,RTAT,PCLT,D,N,R,MUR,
      *MUP,MU,HCR,A1)
C
          INTEGER N,I,NUM(N)
C
          REAL RSR(N),CRR(N),CRT(N),RTAT(N),R,D(N),PCLT(N),QP(N),
      * MU(N),MUR(N),MUP(N),C1(N),HCR,A1
C
          DO 5310  I = 1,N
C
          MUR(I)=(RSR(I)*CRR(I))*(CRT(I)+RTAT(I)+((R-1.)/
      *   (2.*D(I)*RSR(I)*CRR(I))))
C
          MUP(I)=(1.-(RSR(I)*CRR(I)))*(PCLT(I)+((QP(I)-1.))/
      *   (2.*D(I)*(1.-(RSR(I)*CRR(I)))))
C
          MU(I)=(D(I)*(MUR(I)+MUP(I)))
C
 5310    CONTINUE
          RETURN
          END
C
C     **** ROUTINE TO COMPUTE TIME WEIGHTED UNIT SHORT FOR SW ****
C
 7001 SUBROUTINE CPTWUS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,
     *N,R,MU,SW,CTWUS1,CTWUS2,P,C,MSRT,CMSRT,SWR,WT)
C
      INTEGER N,SW(N),K,SWR(N),I,NUM(N)
C
      REAL CTWUS1(N),CTWUS2(N),MU(N),P,C,MSRT,WT(N),ARR(N,10),
     *C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),
```

```
     *CMSRT,QP(N),R
C
      CALL CTWSW0 (PCLT,D,N,MU,SW,CTWUS1,P,C,MSRT,CMSRT,SWR)
C
      IF (CMSRT.LE.MSRT) GO TO 7090
C
      J=1
C
 7005 DO 7080 I=1,N
C
         IF (J.EQ.1) GO TO 7050
         K = SW(I)+ J- 1
         SWR(I)=K
         Z=MU(I)
C
 7010    CALL NORMAL (PCLT,N,Z,K,I,CTWUS)
C
         CTWUS1(I) = CTWUS
 7020    CALL CPMSRT (D,N,CTWUS1,MSRT,CMSRT)
C
         IF (CMSRT.LE.MSRT) GO TO 7090
C
C    **** COMPUTE TIME WEIGHTED UNITS SHORT FOR SW + 1 ****
C
 7050    Z=MU(I)
C
         K=SWR(I)+1
 7060    CALL NORMAL (PCLT,N,Z,K,I,CTWUS)
C
         CTWUS2(I)=CTWUS
C
         IF((J.EQ.1).AND.(I.NE.N)) GO TO 7080
C

 7070    MM=NUM(I)
C
         CALL CPWTS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,
     *   D,N,R,MU,CTWUS1,CTWUS2,SWR,WT)
C
         IF (MM.NE.NUM(I)) GO TO 7075
C
         GO TO 7085
C
 7075    J=SWR(I)+1
C
         GO TO 7085
C
 7080 CONTINUE
C
 7085 J=J+1
      I=1
C
      GO TO 7005
C
 7090 RETURN
      END
C
C    ***** ROUTINE TO COMPUTE TWUS WITH SW=0 *****
C
 7100 SUBROUTINE CTWSW0 (PCLT,D,N,MU,SW,CTWUS1,P,C,MSRT,CMSRT,SWR)
C
      INTEGER N,SW(N),K,SWR(N)
C
      REAL CTWUS1(N),MU(N),P,C,MSRT,Z,D(N),PCLT(N),CMSRT
C
      DO 7130 I=1,N
C
         K=SW(I)
         SWR(I)=K
```

```
          Z=MU(I)
C
 7110    CALL NORMAL (PCLT,N,Z,K,I,CTWUS)
C
          CTWUS1(I)=CTWUS
C
 7120    IF (I.NE.N) GO TO 7130
C
          CALL CPMSRT (D,N,CTWUS1,MSRT,CMSRT)
C
 7130 CONTINUE
      RETURN
      END
C
C    *****ROUTINE TO CALCULATE NORMAL PROBABILITIES AND TWUS*****
C
 7300 SUBROUTINE NORMAL (PCLT,N,Z,K,I,CTWUS)
C
      INTEGER K,I,N
C
      REAL S,Z,T1,T2,CA,CB,PCLT(N),CTWUS
C
      CA = 0.
      CB = 0.
      S=FLOAT(K) + 0.5
C
      T1=(S-Z)/SQRT(Z)
      T2=(S-Z-1.0)/SQRT(Z)
C
      CALL MDNOR (T1,CA)
      CALL MDNOR (T2,CB)
C
      CTWUS=(PCLT(I)/2.)*(CA*(K-(K*(K+1)/Z))-CB*(Z-K)+
     *(Z-2.*K+K*(K+1)/Z))
C
      RETURN
      END
C
C  **** ROUTINE TO COMPUTE MSRT AND COMPARE TO MSRT GOAL ****
C
 7400 SUBROUTINE CPMSRT (D,N,CTWUS1,MSRT,CMSRT)
C
      INTEGER N
C
      REAL CMSRT,D(N),CTWUS1(N),MSRT,CCTWUS,DD
C
      CCTWUS=0.0
C
      DD=0.0
C
      DO 7410 I=1,N
C
         X=CTWUS1(I)
C
         IF(CTWUS1(I).LT.0) X=0.
C
         CCTWUS=CCTWUS + X
C
         DD=DD+D(I)
C
 7410 CONTINUE
C
      CMSRT = CCTWUS / DD
C
      RETURN
      END
C
C    **** ROUTINE TO COMPUTE WEIGHTS AND FIND SMALLEST ****
C
```

```
 7500 SUBROUTINE CPWTS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,
     *PCLT,D,N,R,MU,CTWUS1,CTWUS2,SWR,WT)
C
      INTEGER N,SWR(N),NUM(N)
C
      REAL WT(N),CTWUS1(N),CTWUS2(N),ARR(N,10),QP(N),
     *C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),MU(N),R
C
      DO 7510 I=1,N
C
         WT(I) = C1(I) / (CTWUS1(I) - CTWUS2(I))
C
 7510 CONTINUE
C
      CALL SORTS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,
     *PCLT,D,N,R,MU,CTWUS1,CTWUS2,SWR,WT)
C
      RETURN
      END
C
C     *****ROUTINE TO SORT FROM SMALLEST TO LARGEST*****
C
 7600 SUBROUTINE SORTS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,
     *RTAT,PCLT,D,N,R,MU,CTWUS1,CTWUS2,SWR,WT)
C
      INTEGER N,S4,SWR(N),NN,L,K,NUM(N)
C
      REAL ARR(N,10),C1(N),C2(N),RSR(N),CRR(N),CRT(N),
     *RTAT(N),PCLT(N),D(N),WT(N),MU(N),CTWUS1(N),CTWUS2(N),QP(N),R,
     *S5,S6,S7,S8,S9,S10,S11,S12,S13,S14,S15,S16,S17,S18
C
      NN = N-1
C
      DO 7630 J=1,NN
C
         L=J
         JJ=J+1
         DO 7610 K=JJ,N
            IF (WT(L).LT.WT(K)) GO TO 7610
            L=K
C
 7610    CONTINUE
C
         DO 7620 M=1,N
            S=ARR(L,M)
            ARR(L,M)=ARR(J,M)
            ARR(J,M)=S
C
 7620    CONTINUE
C
         CALL ARRAYS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
         S1=NUM(L)
         NUM(L)=NUM(J)
         NUM(J)=S1
         S4 = SWR(L)
         SWR(L)=SWR(J)
         SWR(J) = S4
         S5=MU(L)
         MU(L)=MU(J)
         MU(J)=S5
         S6=WT(L)
         WT(L)=WT(J)
         WT(J)=S6
         S7=CTWUS1(L)
         CTWUS1(L)=CTWUS1(J)
         CTWUS1(J)=S7
         S8=CTWUS2(L)
         CTWUS2(L)=CTWUS2(J)
         CTWUS2(J)=S8
```

```
      S9=QP(L)
      QP(L) = QP(J)
      QP(J) = S9
      S11 = C1(L)
      C1(L) = C1(J)
      C1(J) = S11
      S12 = C2(L)
      C2(L) = C2(J)
      C2(J) = S12
      S13 = RSR(L)
      RSR(L) = RSR(J)
      RSR(J) = S13
      S14 = CRR(L)
      CRR(L) = CRR(J)
      CRR(J) = S14
      S15 = CRT(L)
      CRT(L) = CRT(J)
      CRT(J) = S15
      S16 = RTAT(L)
      RTAT(L) = RTAT(J)
      RTAT(J) = S16
      S17 = PCLT(L)
      PCLT(L) = PCLT(J)
      PCLT(J) = S17
      S18 = D(L)
      D(L) = D(J)
      D(J) = S18
C
 7630 CONTINUE
      CALL ARRAYS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
      RETURN
      END
C
C     *****ROUTINE TO COMPUTE MINIMUM INTITIAL INVESTMENT*****
C
 8001 SUBROUTINE MINVST (C1,N,SWR,COSTSW,INVEST)
C
      INTEGER N,SWR(N)
C
      REAL INVEST,C1(N),COSTSW(N)
C
      INVEST=0.0
C
      DO 8650 I=1,N
C
         COSTSW(I) = C1(I) * SWR(I)
         INVEST = INVEST + COSTSW(I)
C
 8650 CONTINUE
      RETURN
      END
C
C     *****ROUTINE TO WRITE ALL DATA*****
C
 9001 SUBROUTINE WRITER(ARR,NUM,QP,C1,N,R,MU,CTWUS1,MSRT,
     *CMSRT,SWR,WT,COSTSW,INVEST,D)
C
      INTEGER N,SWR(N),NUM(N)
C
      REAL CMSRT,MSRT,ARR(N,10),
     *MU(N),CTWUS1(N),WT(N),C1(N),COSTSW(N),INVEST,QP(N),R,D(N)
C
      DO 9120 I=1,N
C
 9120 CONTINUE
C
      CMSRT = CMSRT * 91
      MSRT  = MSRT * 91
```

```
C
 9740 WRITE (6,9741) CMSRT,MSRT
C
 9760 WRITE (6,9761)
C
      DO 9762 I=1,N
C
          WRITE (6,9763)(ARR(I,J),J=1,10),MU(I),CTWUS1(I),WT(I),SWR(I)
C
 9762 CONTINUE
 9800 WRITE (6,9890)
C
      DO 9810 I=1,N
C
          WRITE (6,9896) NUM(I),SWR(I),C1(I),COSTSW(I)
C
 9810 CONTINUE
C
      WRITE (6,9898) INVEST
C
 9741 FORMAT ('++++++++++CMSRT:',F10.4,1X,'DAYS',3X,'MSRT:',F10.4,1X,
     *'DAYS','+++++++++++')
C
 9761 FORMAT (5X,'NUM',7X,'QP',7X,'C1',8X,'C2',6X,
     *'RSR',4X,'CRR',4X,'CRT',3X,'RTAT',3X,'PCLT',5X,'D',10X,'MU',7X,
     *'CTWUS1',6X,'WT',6X,'SWR')
C
 9763 FORMAT (2X,I4,1X,F8.2,2F10.2,1X,2(F6.4,1X),F5.2,1X,F8.3,1X,F9.3,
     *1X,F9.3,1X,2(F10.4,1X),E13.4,1X,I5)
C
 9890 FORMAT (20X,'NUM',5X,'SWR',5X,'COST C1',8X,'COSTSW')
C
 9896 FORMAT (17X,I4,2X,I6,2X,F10.2,3X,F14.2)
C
 9898 FORMAT (2X,'**** TOTAL MINIMUM INITIAL INVESTMENT:$',
     *F14.2,2X,'****')
C
      RETURN
      END
```

APPENDIX E

COMPUTER PROGRAM LISTING FOR PROCUREMENT QUANTITY = EOQ

```
C          **** VARIABLE DECLARATION ****
C
        REAL REG1,C1(50),C2(50),MU(50),QP(50),R,MUP(50),MUR(50),RSR(50),
       *CRR(50),CRT(50),RTAT(50),PCLT(50),D(50),WT(50),INVEST,MSRT,
       *CMSRT,ARR(50,10),S,CTWUS1(50),CTWUS2(50),COSTSW(50),S5,S6,S7,
       *S8,S9,S10,S11,S12,S13,S14,S15,S16,S17,S18,CTWUS,ATT
C
        INTEGER S1,S2,S3,SW(50),SWR(50),S4,CG,NUM(50)
C
          N = 0
          I = 1
          II = 0
C
 1      READ (30,30,END=600) CG,PCLT1,RSR1,RTAT1,C11,D1,REG1,C21
C
  30   FORMAT(I1,29X,F4.2,F3.2,F4.2,14X,F10.2,F10.2,F10.2,121X,F10.2,39X)
C
        IF (D1.LT.      ) GO TO 1
         A1 = 1100.00
         HCR = .21
         R = 1.
         MSRT = (87.* (.15))/91.
         CRT1 = (170./365.) * 4.
         CRR1 = REG1/(D1*RSR1)
C
          ATT = D1 - REG1
          IF (ATT.LT.0) GO TO 5
          QP1 = SQRT ((8.* (ATT) * A1) / (HCR * C11))
          GOTO 6
  5      QP1 = 0
C
  6     II = II + 1
         N = N + 1
         NUM(N) = II
         QP(N)   = QP1
         PCLT(N) = PCLT1
         RSR(N)  = RSR1
         CRR(N)  = CRR1
         CRT(N)  = CRT1
         RTAT(N)  = RTAT1
         C1(N)   = C11
         D(N)    = D1
         C2(N)   = C21
C
         GO TO 1
C
 600    CALL ARRAYS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
 5000   CALL COMPMU (NUM,QP,C1,RSR,CRR,CRT,RTAT,PCLT,D,N,R,MUR,MUP,MU,
       *HCR,A1)
C
         DO 6000 I=1,N
         SW(I) = 0
c
 6000   CONTINUE
C
 7000  CALL CPTWUS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N,
       *R,MU,SW,CTWUS1,CTWUS2,P,C,MSRT,CMSRT,SWR,WT)
C
 8000  CALL MINVST (C1,N,SWR,COSTSW,INVEST)
```

```
C
 9000 CALL WRITER (ARR,NUM,QP,C1,N,R,MU,CTWUS1,MSRT,CMSRT,SWR,WT,
     *COSTSW,INVEST,D)
C
99999  STOP
        END
C
C   *******************************************************************
C                   END OF MAIN PROGRAM
C   *******************************************************************
```

APPENDIX F

PROCUREMENT QUANTITY LARGER OF EOQ OR ANNUAL DEMAND

```
C          **** VARIABLE DECLARATION ****
C
       REAL REG1,C1(50),C2(50),MU(50),QP(50),R,MUP(50),MUR(50),RSR(50),
      *CRR(50),CRT(50),RTAT(50),PCLT(50),D(50),WT(50),INVEST,MSRT,
      *CMSRT,ARR(50,10),S,CTWUS1(50),CTWUS2(50),COSTSW(50),S5,S6,S7,
      *S8,S9,S10,S11,S12,S13,S14,S15,S16,S17,S18,CTWUS,ATT,QPA,QPE
C
       INTEGER S1,S2,S3,SW(50),SWR(50),S4,CG,NUM(50)
C
         N = 0
         I = 1
         II = 0
C
 1     READ (30,30,END=600) CG,PCLT1,RSR1,RTAT1,C11,D1,REG1,C21
C
  30  FORMAT(I1,29X,F4.2,F3.2,F4.2,14X,F10.2,F10.2,F10.2,121X,F10.2,39X)
C
       IF (D1.LT.     ) GO TO 1
        A1 = 1100.00
        HCR = .21
        R = 1.
        MSRT = (87.* (.15))/91.
        CRT1 = (170./365.) * 4.
        CRR1 = REG1/(D1*RSR1)
C
         ATT = D1 - REG1
         IF (ATT.LT.0) GO TO 5
c ***********************************************************
         QPE = SQRT ((8.* (ATT) * A1) / (HCR * C11))
         QPA = (4.* (ATT))
         QP1 = AMAX1 (QPE,QPA)
c ***********************************************************
         GOTO 6
  5     QP1 = 0
C
  6    II = II + 1
        N = N + 1
        NUM(N) = II
        QP(N)   = QP1
        PCLT(N) = PCLT1
        RSR(N)  = RSR1
        CRR(N)  = CRR1
        CRT(N)  = CRT1
        RTAT(N)  = RTAT1
        C1(N)   = C11
        D(N)    = D1
        C2(N)   = C21
C
        GO TO 1
C
 600   CALL ARRAYS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
C
 5000  CALL COMPMU (NUM,QP,C1,RSR,CRR,CRT,RTAT,PCLT,D,N,R,MUR,MUP,MU,
      *HCR,A1)
C
        DO 6000 I=1,N
        SW(I) = 0
c
 6000  CONTINUE
C
 7000 CALL CPTWUS (ARR,NUM,QP,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N,
```

```
     *R,MU,SW,CTWUS1,CTWUS2,P,C,MSRT,CMSRT,SWR,WT)
C
 8000 CALL MINVST (C1,N,SWR,COSTSW,INVEST)
C
 9000 CALL WRITER (ARR,NUM,QP,C1,N,R,MU,CTWUS1,MSRT,CMSRT,SWR,WT,
     *COSTSW,INVEST,D)
C
99999  STOP
       END
C
C  *****************************************************************
C                  END OF MAIN PROGRAM
C  *****************************************************************
```

APPENDIX G

2R COG - ECONOMIC ORDER QUANTITY

++++++++++CMSRT: 13.0431 DAYS MSRT: 13.0500 DAYS++++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
2	156.24	105.00	0.8300	1.0000	0.480	5.000	1062.290	3046.4045	325.0183
1	168.76	52.85	0.8700	1.0000	0.480	5.000	710.980	1995.2991	43.4557
7	361.96	125.00	0.4400	0.8864	0.480	4.050	1317.200	4638.2383	419.3904
4	763.73	42.50	0.7200	0.7361	0.480	5.000	3050.360	11337.6328	141.2012
6	306.90	45.50	0.7000	0.7714	0.480	5.000	884.390	3305.9993	121.9836
10	255.11	62.10	0.3900	0.7179	1.050	4.600	612.610	2655.6934	258.7812
9	45.21	183.00	0.9900	1.0000	0.480	7.330	789.580	1915.4456	39.4957
8	534.75	32.50	0.4900	0.7959	0.480	5.000	671.210	2927.4045	14.1584
3	452.14	30.25	0.6800	0.6471	0.480	5.000	966.960	3929.9246	55.7873
5	347.97	259.38	0.6000	0.9833	0.620	6.490	711.800	3110.2925	30.2159
11	156.26	384.50	0.8500	0.9874	0.820	*****	1167.450	4644.6328	262.5750

NUM	SWR	COST C1	COSTSW
2	2419	310.00	749890.00
1	1814	136.00	246704.00
7	3660	257.00	940620.00
4	10544	103.00	1086032.00
6	2908	181.00	526348.00
10	2111	284.00	599524.00
9	1783	162.00	288846.00
8	2810	60.00	168600.00
3	3640	111.00	404040.00
5	2949	101.00	297849.00
11	4163	322.00	1340486.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 6,648,939.00 ****

APPENDIX H

2R COG - ANNUAL ATTRITION DEMAND

+++++++++CMSRT: 13.0499 DAYS MSRT: 13.0500 DAYS+++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
2	722.36	105.00	0.8300	1.0000	0.480	5.000	1062.290	3329.4639	298.5974
10	1764.32	62.10	0.3900	0.7179	1.050	4.600	612.610	3410.2979	279.2344
6	1627.28	45.50	0.7000	0.7714	0.480	5.000	884.390	3966.1904	122.7020
5	1167.36	259.38	0.6000	0.9833	0.620	6.490	711.800	3519.9866	28.7942
7	3213.96	125.00	0.4400	0.8864	0.480	4.050	1317.200	6064.2383	462.0552
4	5734.68	42.50	0.7200	0.7361	0.480	5.000	3050.360	13823.1133	144.6582
8	1637.76	32.50	0.4900	0.7959	0.480	5.000	671.210	3478.9089	13.9701
1	369.72	52.25	0.8700	1.0000	0.480	5.000	710.980	2095.7791	38.3159
9	31.60	188.00	0.9900	1.0000	0.480	7.330	789.520	1908.6428	53.5166
11	750.48	384.50	0.8500	0.9874	0.820	*****	1167.450	4941.7461	233.3316
3	2166.00	30.25	0.6800	0.6471	0.480	5.000	966.960	4786.8555	37.7734

NUM	SWR	COST C1	COSTSW
2	2701	310.00	837310.00
10	2769	284.00	786396.00
6	3529	181.00	638749.00
5	3353	101.00	338653.00
7	4890	257.00	1256730.00
4	12936	103.00	1332408.00
8	3352	60.00	201120.00
1	1922	136.00	261392.00
9	1788	162.00	289656.00
11	4474	322.00	1440628.00
3	4461	111.00	495171.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 7,878,213.00 ****

APPENDIX I

2R COG - Q = 1.0

+++++++++CMSRT: 13.0459 DAYS MSRT: 13.0500 DAYS++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTNUS1
10	1.00	62.10	0.3900	0.7179	1.050	4.600	612.610	2528.6372	256.008
11	1.00	384.50	0.8500	0.9874	0.820	10.330	1167.450	4567.0078	268.461
7	1.00	125.00	0.4400	0.8864	0.480	4.050	1317.200	4457.7617	418.289
2	1.00	105.00	0.8300	1.0000	0.480	5.000	1062.290	2968.7834	329.638
6	1.00	45.50	0.7000	0.7714	0.480	5.000	884.390	3153.0510	120.973
3	1.00	30.25	0.6800	0.6471	0.480	5.000	966.960	3704.3564	54.978
8	1.00	32.50	0.4900	0.7959	0.480	5.000	671.210	2660.5293	13.451
9	1.00	188.00	0.9900	1.0000	0.480	7.830	789.580	1893.3428	40.402
1	1.00	52.85	0.8700	1.0000	0.480	5.000	710.980	1911.4189	42.976
5	1.00	259.38	0.6000	0.9833	0.620	6.490	711.300	2936.8064	29.551
4	1.00	42.50	0.7200	0.7361	0.480	5.000	3050.360	10956.2734	137.693

NUM	SWR	COST C1	COSTSW
10	2000	284.00	568000.00
11	4084	322.00	1315048.00
7	3500	257.00	899500.00
2	2345	310.00	726950.00
6	2766	181.00	500646.00
3	3425	111.00	380175.00
8	2552	60.00	153120.00
9	1760	162.00	285120.00
1	1735	136.00	235960.00
5	2782	101.00	280982.00
4	10186	103.00	1049158.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 6,394,659.00 ****

APPENDIX J

7H COG - ECONOMIC ORDER QUANTITY

+++++++++CMSRT: 13.0401 DAYS MSRT: 13.0500 DAYS+++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTNUS1
1	86.93	4540.43	0.9000	0.0000	2.270	3.330	2331.660	19465.6875	716.1033
10	18.33	575.00	0.9800	0.9796	0.900	15.210	284.380	936.0513	1.3346
6	115.48	498.00	0.9500	0.0000	2.270	7.670	365.990	2864.3843	2.4248
5	106.96	100.00	0.8500	1.0000	1.930	12.130	449.500	2320.0996	0.2900
7	31.50	219.00	0.9700	1.0000	1.470	15.000	465.790	1730.7195	0.6584
3	28.31	374.07	0.8100	1.0998	2.270	9.430	205.050	979.6768	1.1919
8	46.87	384.00	0.8500	0.9059	2.270	8.780	264.390	1398.2441	1.4747
4	81.21	322.05	0.9000	0.4705	1.270	4.000	261.780	991.1296	1.1525
2	82.03	322.05	0.9000	0.4655	1.270	4.000	265.010	1004.2915	1.1605
9	17.10	518.00	0.9800	0.9694	1.390	8.000	178.630	631.5254	1.0396

NUM	SNR	COST C1	COSTSW
1	17641	12930.00	228098128.00
10	954	1420.00	1354680.00
6	2856	1150.00	3284400.00
5	2377	247.00	587119.00
7	1769	590.00	1043710.00
3	992	1170.00	1160640.00
8	1407	1160.00	1632120.00
4	988	959.00	947492.00
2	1001	959.00	959959.00
9	641	1280.00	820480.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 239,883,672.00 ****

APPENDIX K

7H COG - ANNUAL ATTRITION DEMAND

+++++++++CMSRT: 13.0462 DAYS MSRT: 13.0500 DAYS++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
1	9326.64	4540.43	0.9000	0.0000	2.270	8.330	2331.660	24085.5469	717.4700
9	35.72	518.00	0.9800	0.9694	1.390	8.000	178.630	640.8364	0.9245
8	243.24	384.00	0.8500	0.9059	2.270	8.780	264.390	1496.4292	1.3174
6	1463.96	498.00	0.9500	0.0000	2.270	7.670	365.990	3538.6230	2.3245
4	603.76	322.05	0.9000	0.4705	1.270	4.000	261.780	1252.4033	1.1485
2	615.92	322.05	0.9000	0.4655	1.270	4.000	265.010	1271.2383	1.1393
7	55.88	219.00	0.9700	1.0000	1.470	15.000	465.790	1742.9097	0.5394
10	45.52	575.00	0.9800	0.9796	0.900	15.210	284.380	949.6482	1.0789
5	269.72	100.00	0.8500	1.0000	1.930	12.130	449.500	2401.4810	0.2411
3	89.52	374.07	0.8100	1.0998	2.270	9.430	205.050	1010.2808	0.9884

NUM	SWR	COST C1	COSTSW
1	22054	12930.00	285158144.00
9	652	1230.00	834560.00
8	1508	1160.00	1749280.00
6	3531	1150.00	4060650.00
4	1249	959.00	1197791.00
2	1268	959.00	1216012.00
7	1785	590.00	1053150.00
10	971	1420.00	1378820.00
5	2463	247.00	608361.00
3	1026	1170.00	1200420.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 298,456,320.00 ****

APPENDIX L

7H COG - Q = 1.0

+++++++++CMSRT: 13.0500 DAYS MSRT: 13.0500 DAYS+++++++++++

NUM	QP	CC	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
1	1.00	4540.43	0.9000	0.0000	2.270	8.330	2331.660	19422.7266	716.9656
8	1.00	384.00	0.8500	0.9059	2.270	8.780	264.390	1375.3096	1.4739
6	1.00	498.00	0.9500	0.0000	2.270	7.670	365.990	2807.1431	2.3462
5	1.00	100.00	0.8500	1.0000	1.930	12.130	449.500	2267.1213	0.2805
7	1.00	219.00	0.9700	1.0000	1.470	15.000	465.790	1715.4697	0.6436
2	1.00	322.05	0.9000	0.4655	1.270	4.000	265.010	963.7781	1.1348
9	1.00	518.00	0.9800	0.9694	1.390	8.000	178.630	623.4763	1.0314
10	1.00	575.00	0.9800	0.9796	0.900	15.210	284.380	927.3884	1.2717
3	1.00	374.07	0.8100	1.0993	2.270	9.430	205.050	966.0208	1.1409
4	1.00	322.05	0.9000	0.4705	1.270	4.000	261.780	951.0232	1.0937

NUM	SWR	COST C1	COSTSW
1	17599	12930.00	227555056.00
8	1384	1160.00	1605440.00
6	2800	1150.00	3220000.00
5	2324	247.00	574028.00
7	1754	590.00	1034860.00
2	961	959.00	921599.00
9	633	1280.00	810240.00
10	946	1420.00	1343320.00
3	979	1170.00	1145430.00
4	949	959.00	910091.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 239,120,000.00 ****

APPENDIX M

7G COG - ECONOMIC ORDER QUANTITY

+++++++++CMSRT: 13.0479 DAYS MSRT: 13.0500 DAYS+++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTNUS1
1	18.75	1697.00	0.9000	0.9000	2.270	8.130	297.170	1462.7510	476.3591
2	78.74	264.97	0.9000	0.3473	2.270	6.600	226.000	1356.2029	16.4908
10	25.26	286.00	0.9800	0.9796	0.630	4.500	434.140	1129.2371	21.2993
14	38.83	275.00	0.9800	0.9480	0.960	8.970	1089.920	3571.3633	111.4603
13	54.28	200.00	0.9400	0.9841	1.300	15.350	928.530	3811.8057	20.6996
11	21.14	583.00	0.9900	0.9798	0.620	13.740	878.040	2486.7622	70.9140
3	0.00	213.39	0.9000	3.8804	2.270	6.600	192.830	339.1875	4.7097
9	19.40	480.00	0.9500	0.9934	0.980	6.340	257.190	790.9602	21.9421
4	0.00	473.58	0.9200	3.4930	2.270	6.600	216.370	223.4741	12.1810
12	16.72	205.00	0.9400	0.9894	0.970	7.770	187.790	604.7422	21.3891
8	12.57	125.00	1.0000	0.9900	0.620	7.030	330.190	840.6567	3.2105
3	35.94	240.00	0.9500	0.8316	0.770	5.000	196.670	633.0598	15.5703
6	19.58	263.00	0.9900	0.9798	0.800	4.800	270.460	746.8604	9.2649
5	0.00	474.76	0.9000	3.4977	2.270	6.600	226.000	264.0122	11.3524

NUM	SWR	COST C1	COSTSW
1	1050	6730.00	7066500.00
2	1282	1050.00	1346100.00
10	1031	1140.00	1175340.00
14	3279	2150.00	7049850.00
13	3730	990.00	3692700.00
11	2334	2470.00	5764980.00
3	374	838.00	313412.00
9	722	1610.00	1162420.00
4	260	1880.00	488800.00
12	552	1970.00	1087440.00
8	806	875.00	705250.00
7	575	1340.00	770500.00
6	700	886.00	620200.00
5	238	1890.00	449820.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 31,693,264.00 ****

APPENDIX N

7G COG - ANNUAL ATTRITION DEMAND

+++++++++CMSRT: 13.0429 DAYS MSRT: 13.0500 DAYS+++++++++++

NUM	QP	CC	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
14	309.48	275.00	0.9800	0.9480	0.960	8.970	1089.920	3706.6865	109.2025
13	278.40	200.00	0.9400	0.9841	1.300	15.350	923.530	3923.8667	20.3263
1	225.84	1697.00	0.9000	0.9000	2.270	8.130	297.170	1566.2961	483.4788
7	165.20	240.00	0.9500	0.8316	0.770	5.000	196.670	697.6909	16.3479
10	69.44	286.00	0.9800	0.9796	0.630	4.500	434.140	1151.3762	20.5871
6	32.44	263.00	0.9900	0.9798	0.800	4.800	270.460	753.2878	9.0356
11	105.36	583.00	0.9900	0.9798	0.620	13.740	873.040	2528.8726	68.2919
12	52.56	205.00	0.9400	0.9894	0.970	7.770	137.790	622.6631	20.8314
2	621.44	264.97	0.9000	0.3473	2.270	6.600	226.300	1627.5520	17.9465
4	0.00	473.58	0.9200	3.4930	2.270	6.600	216.870	283.4741	11.5441
9	57.84	480.00	0.9500	0.9934	0.980	6.340	257.190	810.1302	21.0793
3	0.00	213.39	0.9000	3.8804	2.270	6.600	192.330	389.1875	4.4256
8	13.20	125.00	1.0000	0.9900	0.620	7.030	330.190	840.9709	7.7152
5	0.00	474.76	0.9000	3.4977	2.270	6.600	226.300	264.0122	10.7169

NUM	SWR	COST CI	COSTSW
14	3412	2150.00	7335800.00
13	3842	990.00	3803580.00
1	1136	6730.00	7645280.00
7	635	1340.00	850900.00
10	1054	1140.00	1201560.00
6	707	886.00	626402.00
11	2378	2470.00	5873660.00
12	570	1970.00	1122900.00
2	1542	1050.00	1619100.00
4	261	1880.00	490680.00
9	742	1610.00	1194620.00
3	375	838.00	314250.00
8	808	875.00	707000.00
5	239	1890.00	451710.00

********** TOTAL MINIMUM INITIAL INVESTMENT:$ 33,237,344.00 ****

APPENDIX O

7G COG - Q = 1.0

++++++++++CMSRT: 13.0455 DAYS MSRT: 13.0500 DAYS+++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
1	1.00	1697.00	0.9000	0.9000	2.270	8.130	297.170	1453.8762	477.2275
14	1.00	275.00	0.9800	0.9480	0.960	8.970	1089.920	3552.4468	112.0910
9	1.00	480.00	0.9500	0.9934	0.980	6.340	257.190	781.7603	22.0521
2	1.00	264.97	0.9000	0.3473	2.270	6.600	226.000	1317.3320	16.1969
8	1.00	125.00	1.0000	0.9900	0.620	7.030	330.190	834.8708	8.3102
11	1.00	583.00	0.9900	0.9798	0.620	13.740	878.040	2476.6921	71.1154
13	1.00	200.00	0.9400	0.9841	1.300	15.350	928.530	3785.1675	20.5798
10	1.00	286.00	0.9800	0.9796	0.630	4.500	434.140	1117.1565	21.0630
6	1.00	263.00	0.9900	0.9798	0.800	4.800	270.460	737.5679	9.2643
7	1.00	240.00	0.9500	0.8316	0.770	5.000	196.670	615.5908	15.2631
12	1.00	205.00	0.9400	0.9894	0.970	7.770	187.790	596.8331	21.0396
4	1.00	473.58	0.9200	3.4930	2.270	6.600	216.870	287.9741	11.8749
3	1.00	213.39	0.9000	3.3804	2.270	6.600	192.830	383.6873	4.5685
5	1.00	474.76	0.9000	3.4977	2.270	6.600	226.000	263.5120	11.0466

NUM	SWR	COST C1	COSTSW
1	1042	6730.00	7012660.00
14	3260	2150.00	7009000.00
9	713	1610.00	1147930.00
2	1245	1050.00	1307250.00
8	800	875.00	700000.00
11	2324	2470.00	5740280.00
13	3704	990.00	3666960.00
10	1020	1140.00	1162800.00
6	691	886.00	612226.00
7	559	1340.00	749060.00
12	545	1970.00	1073650.00
4	260	1880.00	488800.00
3	374	838.00	313412.00
5	238	1890.00	449820.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 31,433,208.00 ****

APPENDIX P

7H COG - INVESTMENT LEVELS WHEN MSRT GOAL IS 1 DAY

+++++++++CMSRT: 0.9969 DAYS MSRT: 1.0000 DAYS++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
1	9326.64	4540.43	0.9000	0.0000	2.270	8.330	2331.660	24085.5469	53.6566
9	35.72	518.00	0.9800	0.9694	1.390	8.000	178.630	640.8364	0.1790
4	603.76	322.05	0.9000	0.4705	1.270	4.000	261.780	1252.4033	0.2235
2	615.92	322.05	0.9000	0.4655	1.270	4.000	265.010	1271.2383	0.2242
8	243.24	384.00	0.8500	0.9059	2.270	8.780	264.390	1496.4292	0.2694
3	89.52	374.07	0.8100	1.0998	2.270	9.430	205.050	1010.2808	0.2006
6	1463.96	498.00	0.9500	0.0000	2.270	7.670	365.990	3538.6230	0.4423
7	55.28	219.00	0.9700	1.0000	1.470	15.000	465.790	1742.9097	0.1097
10	45.52	575.00	0.9800	0.9796	0.900	15.210	284.380	949.6482	0.2114
5	269.72	100.00	0.8500	1.0000	1.930	12.130	449.500	2401.4810	0.0515

NUM	SWR	COST C1	COSTSW
1	23550	12930.00	304501248.00
9	671	1230.00	853880.00
4	1281	959.00	1228479.00
2	1300	959.00	1246700.00
8	1538	1160.00	1784080.00
3	1049	1170.00	1227330.00
6	3586	1150.00	4123900.00
7	1810	590.00	1067900.00
10	992	1420.00	1408640.00
5	2489	247.00	614783.00

***** TOTAL MINIMUM INITIAL INVESTMENT:$ 318,060,800.00 ****

APPENDIX Q

7H COG - INVESTMENT LEVELS WHEN MSRT GOAL IS 7 DAYS

++++++++CMSRT: 6.9963 DAYS MSRT: 7.0000 DAYS++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTWUS1
1	9326.64	4540.43	0.9000	0.0000	2.270	8.330	2331.660	24085.5469	383.4238
6	1463.96	498.00	0.9500	0.0000	2.270	7.670	365.990	3538.6230	1.5570
8	243.24	384.00	0.8500	0.9059	2.270	8.780	264.390	1496.4292	0.9022
10	45.52	575.00	0.9800	0.9796	0.900	15.210	284.380	949.6482	0.7653
4	603.76	322.05	0.9000	0.4705	1.270	4.000	261.780	1252.4033	0.7639
2	615.92	322.05	0.9000	0.4655	1.270	4.000	265.010	1271.2383	0.7596
3	89.52	374.07	0.8100	1.0998	2.270	9.430	205.050	1010.2808	0.6823
9	35.72	518.00	0.9800	0.9694	1.390	8.000	178.630	640.8364	0.5300
5	269.72	100.00	0.2500	1.0000	1.930	12.130	449.500	2401.4810	0.1657
7	55.88	219.00	0.9700	1.0000	1.470	15.000	465.790	1742.9097	0.3609

NUM	SWR	COST C1	COSTSW
1	22604	12930.00	292269568.00
6	3546	1150.00	4077900.00
8	1516	1160.00	1758560.00
10	976	1420.00	1385920.00
4	1258	959.00	1206422.00
2	1277	959.00	1224643.00
3	1032	1170.00	1207440.00
9	658	1280.00	842240.00
5	2470	247.00	610090.00
7	1792	590.00	1057280.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 305,639,168.00 ****

APPENDIX R

7H COG - INVESTMENT LEVELS WHEN MSRT GOAL IS 21 DAYS

+++++++++CMSRT: 20.9917 DAYS MSRT: 21.0000 DAYS+++++++++++

NUM	QP	C2	RSR	CRR	RTAT	PCLT	D	MU	CTHUS
1	9326.64	4540.43	0.9000	0.0000	2.270	8.330	2331.660	24085.5469	1156.1453
6	1463.96	498.00	0.9500	0.0000	2.270	7.670	365.990	3538.6230	3.3567
7	55.88	219.00	0.9700	1.0000	1.470	15.000	465.790	1742.9097	0.7841
3	89.52	374.07	0.8100	1.0993	2.270	9.430	205.050	1010.2808	1.4749
2	615.92	322.05	0.9000	0.4655	1.270	4.000	265.010	1271.2383	1.6523
8	243.24	384.00	0.8500	0.9059	2.270	8.720	264.390	1496.4292	1.3717
10	45.52	575.00	0.9800	0.9796	0.900	15.210	284.330	949.6482	1.5827
4	603.76	322.05	0.9000	0.4705	1.270	4.000	261.780	1252.4033	1.6034
5	269.72	100.00	0.8500	1.0000	1.930	12.130	449.500	2431.4810	0.3431
9	35.72	513.00	0.9800	0.9694	1.390	3.000	178.630	640.8364	1.2292

NUM	SWR	COST C1	COSTSW
1	21504	12930.00	278046720.00
6	3516	1150.00	4043400.00
7	1778	590.00	1049020.00
3	1019	1170.00	1192230.00
2	1259	959.00	1207381.00
8	1500	1160.00	1740000.00
10	965	1420.00	1370300.00
4	1241	959.00	1190119.00
5	2456	247.00	606632.00
9	648	1280.00	829440.00

**** TOTAL MINIMUM INITIAL INVESTMENT:$ 291,273,984.00 ****

APPENDIX S

NUM TO NIIN CROSS REFERENCE

2R COG

NUM	NIIN
1	000614108
2	009284502
3	005800999
4	000519925
5	002881397
6	009350771
7	001654043
8	002775398
9	001065464
10	001598648
11	010468387

7H COG

NUM	NIIN
1	011873883
2	LLTA50854
3	011406829
4	LLTA50855
5	010241753
6	011726038
7	010311291
8	006162857
9	010848045
10	010395592

7G COG

NUM	NIIN
1	LLHHH1149
2	011908515
3	011908516
4	011908522
5	011908523
6	000750493
7	000784721
8	000784725
9	003851396
10	007608922
11	009811598
12	009811599
13	010555294
14	011310022

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